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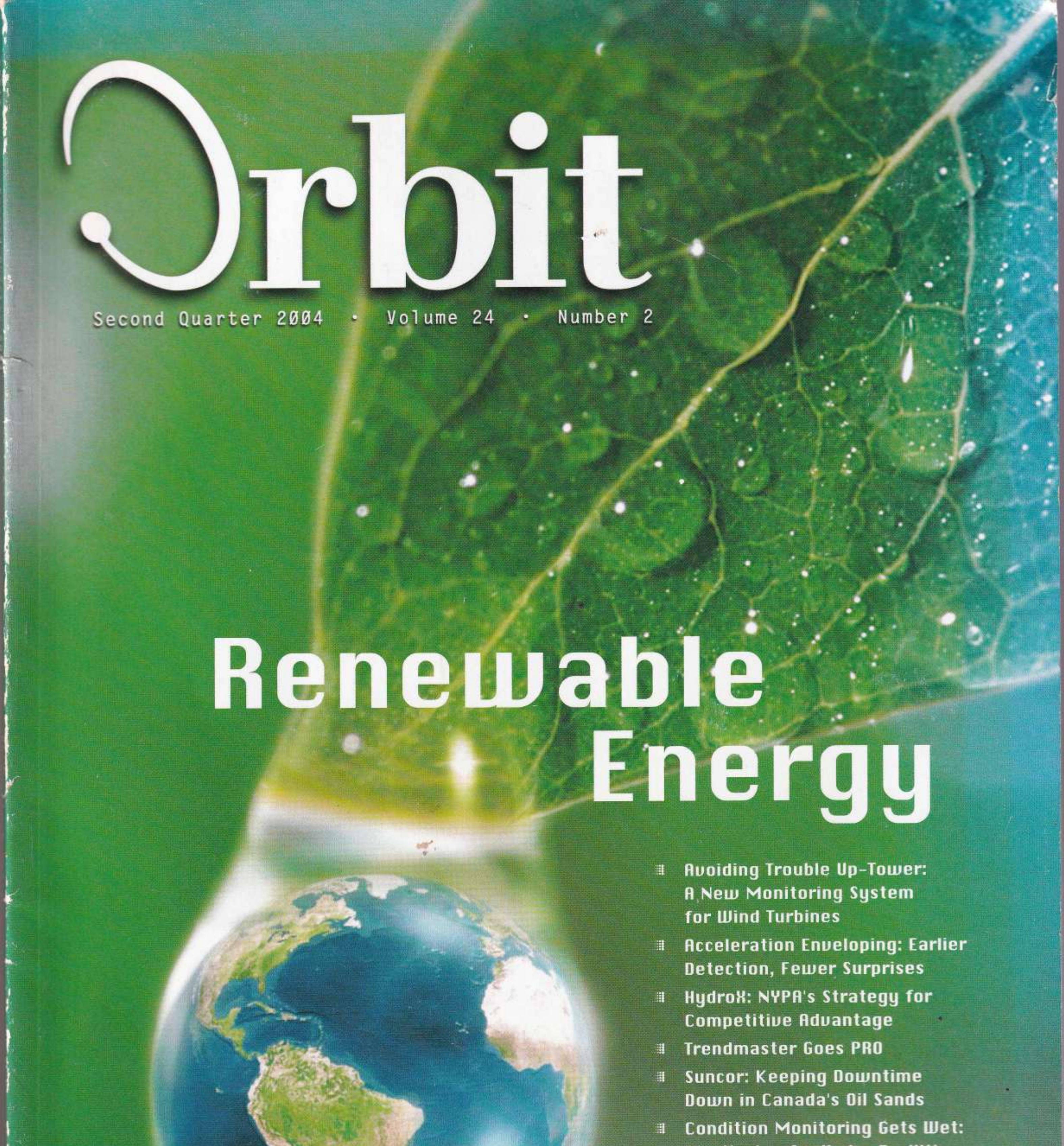

Renewable Energy

- Avoiding Trouble Up-Tower: A New Monitoring System for Wind Turbines
- Acceleration Enveloping: Earlier Detection, Fewer Surprises
- HydroX: NYPA's Strategy for Competitive Advantage
- Trendmaster Goes PRO
- Suncor: Keeping Downtime Down in Canada's Oil Sands
- Condition Monitoring Gets Wet: Monitoring for Hydro Facilities
- 3300 Series Monitors: Alive and Well

Orbit

A Technical Publication for Advancing
the Practice of Operating Asset
Condition Monitoring, Diagnostics,
and Performance Optimization

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Cool Machines

I like machines. Having spent many hours during my formative years with my head buried under a hood in my grandfather's auto repair shop, I just grew up thinking mechanical things were cool.

I can't quite explain, then, why I ended up with an electrical engineering degree rather than mechanical, but the fascination with machines has never left. And that's why preparing this issue of ORBIT has been so enjoyable. As you can gather from the cover, we pay special attention in this issue to some of the machines that generate electricity from renewable resources – specifically, wind and water – giving me the perfect excuse to indulge a fascination with hydro turbine-generators, as well as wind turbines.

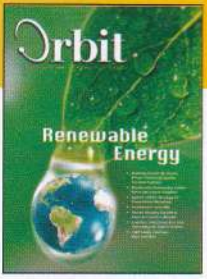
Western Canada, where I began my career, has a large concentration of hydropower facilities. The plants and machines were always a marvel, perhaps because of their immense size. While fun to visit such facilities, it was difficult at that time to sell the need for condition monitoring on these machines. But that was 15 years ago, and as we note in our article beginning on page 48, the power generation world has changed significantly. Market forces cause hydro units to be run more aggressively today, and hydro operators are embracing condition monitoring under these new realities.

And wind? I always wondered about these machines, so graceful in their apparent simplicity. In this issue, I've learned about wind turbines from the stories our authors have contributed, as well as the reasons why condition monitoring makes sense. Wind turbine technology has come a long way in just a few short years with bigger, more sophisticated machines. Wind power is no longer a novelty with 1.5MW machines now commonplace, huge 3+MW machines starting to appear, and 5+MW machines soon to follow. I hope you'll enjoy learning about these machines and the monitoring solutions we have to offer as much as I did, beginning with our article on page 20.

Steve Sabin
Editor

Coming in the Next Issue of ORBIT…

A special focus on:
- Gas Turbines
- System 1® 5.0



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PAYBACK PROFILE:

Suncor Uses Bently Nevada to Increase Profitability – Part 2

Using process data correlation to resolve a chronic vibration problem

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Editor's Note: *Part 1 of this article appeared on page 44 in the First Quarter 2003 issue of ORBIT and chronicled some of the savings realized by Suncor during the five years since the system was first installed. Part 2 continues with another example of how the system has benefitted Suncor.*

System Overview

In 1998, Suncor's Upgrading Operations combined forces with Bently Nevada to undertake a major Machinery Protection System project titled the Continuous Vibration Monitoring Project (CVMP). The first phase of the CVMP included the upgrade of ten pump/compressor trains with one 3300 Series monitoring system per train. Bently Nevada was the engineering contractor for this project and provided many services, such as system engineering, electrical design/labor/materials, mechanical design,

About Suncor

Suncor Energy Inc. is a growing, integrated energy company, strategically focused on developing one of the world's largest petroleum resource basins – Canada's Athabasca oil sands. In the 37 years since history was made by tapping oil sands to produce the first commercial barrel of synthetic crude oil, Suncor has grown to four major business divisions and 4,000 employees.

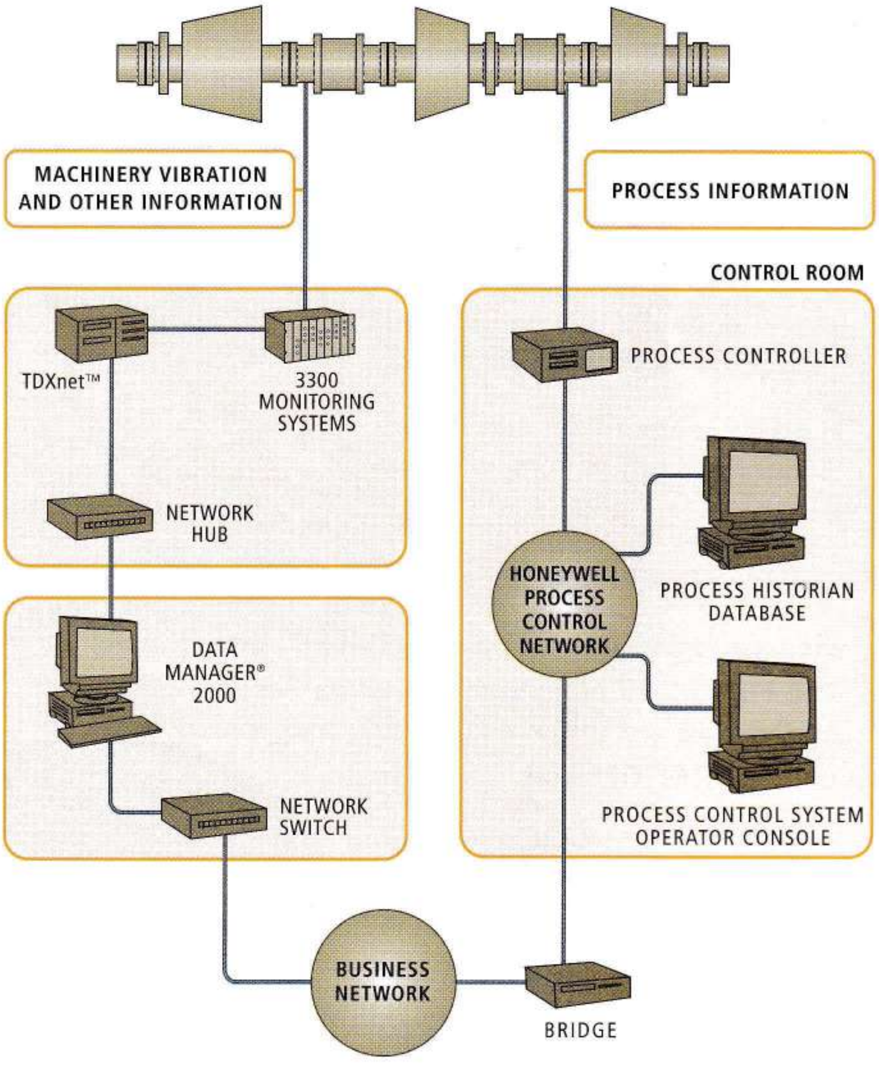
Near Fort McMurray in northern Alberta, Suncor recovers bitumen from oil sand and upgrades it to refinery-ready feedstock and diesel fuel. Suncor pioneered the world's first commercially successful oil sands operation in 1967 and maintains a leading position in Canada's oil sands industry. In 2003, expanded mining and upgrading facilities contributed to record production of an average 216,600 barrels of oil per day.

Construction is underway for the next phase of oil sands growth, which is expected to deliver production capacity of 260,000 barrels per day in 2005, growing in stages to a goal of up to 550,000 barrels per day by 2010 to 2012.

> A **CHRONIC VIBRATION PROBLEM** ON 7K10 HAD **PLAGUED** THE MACHINE FOR **SOME TIME**

project management, documentation, and overall site supervision. Installation and commissioning of this complex operation required the coordination of many Bently Nevada departments, including Manufacturing, Project Engineering, Mechanical Engineering, Systems and Instrumentation, Machinery Management Services, System Integration Engineering, and Training. Phase one was completed in October 1998.

Phase two of the CVMP was completed in May 1999 and included the installation of a Data Manager® 2000 (DM2000) data acquisition, diagnostics, and trending system for a total of 18 machines. In addition to the vibration data available from the DM2000 system, process data is integrated from the plant's process historian database (Honeywell PHD) via an OPC client/server link. This link allows operations and maintenance personnel to correlate process data with vibration information to better understand the health of their machinery. The DM2000 system is also connected to the corporate LAN allowing Suncor personnel to view the live machinery dynamic information from their office workstations. Figure 1 shows the system arrangement.



SYSTEM ARRANGEMENT. | FIG. 1

A Recurring Vibration Problem on Compressor 7K10

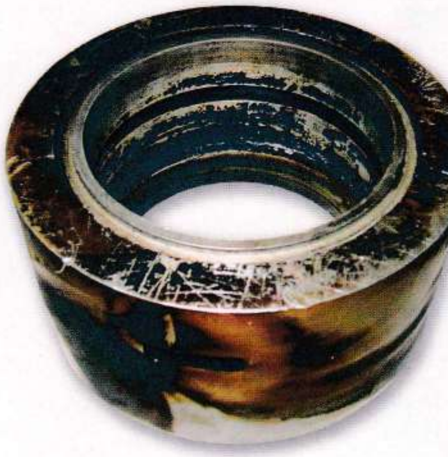
Part 1 of this article described how Suncor used their Bently Nevada condition monitoring system (referred to as the CVMP by Suncor) to identify rotor damage on Kerosene Recycle Compressor 7K10 and resolve these problems without the need for an unplanned outage, saving in excess of $1 million CDN. However, the same compressor has also suffered from a chronic vibration problem for the past few years. This article examines the problem and its resolution using information provided by the CVMP.

The Cycle

A chronic vibration problem on 7K10 had plagued the machine for some time. It typically followed a predictable sequence of events, lasting approximately 6 months, as follows:

MONTH	ACTIVITY
1	The unit is put in service after an overhaul and/or seal/bearing work.
1 – 4	Vibration amplitudes typically remain at very acceptable levels (less than 1 mil), well below alarm limits.
4 – 6	1X vibration amplitude in both X- and Y- planes of the compressor inboard bearing begins to gradually increase for 1 to 2 months, eventually reaching alarm limits.
6	Unit is opened for inspection; hard, varnish-like depositions are sometimes found on seal components (Figure 2) that result in reduced clearances at the seal's dual bushing.

VIBRATION BEGINS TO GRADUALLY **INCREASE** FOR 1 TO 2 MONTHS, EVENTUALLY REACHING **ALARM LIMITS**



VARNISH DEPOSITION ON THE OUTER SEAL (DUAL) BUSHING.

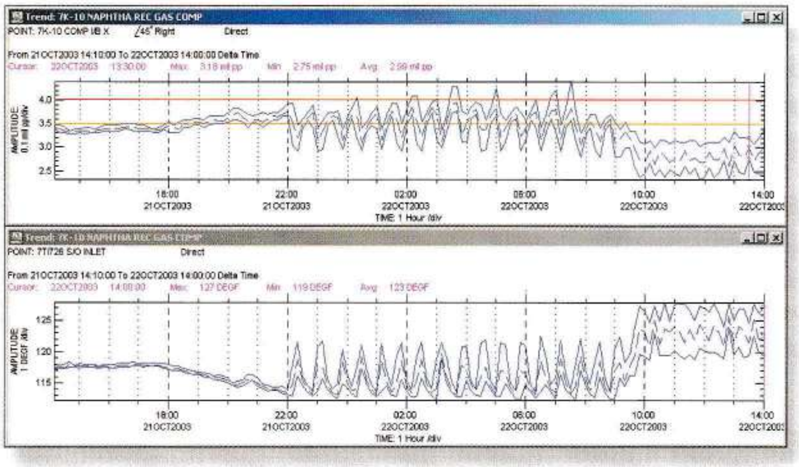
FIG. 2

Using DM2000 for a Closer Look

In October 2003, the chronic problem described above resurfaced with vibration amplitudes at the compressor inboard bearing reaching ALERT and then eventually DANGER levels. Eager to find the root cause of this recurring problem, Suncor carried out a complete analysis using data collected by their DM2000 system.

A significant aspect of Suncor's installation was the integration of process data into their CVMP, allowing them to correlate mechanical health indicators (such as vibration and bearing temperatures) with process-related conditions. Upon investigation, Suncor identified an inverse correlation between the vibration amplitude at the compressor's inboard bearing and the seal oil inlet temperature – the lower the inlet temperatures, the higher the vibration amplitudes (Figure 3).

EAGER TO FIND THE **ROOT CAUSE** OF THIS RECURRING PROBLEM, SUNCOR CARRIED OUT A **COMPLETE ANALYSIS** USING DATA COLLECTED BY THEIR DM2000 SYSTEM



TRENDS SHOWING INVERSE CORRELATION BETWEEN VIBRATION AMPLITUDE AND SEAL OIL INLET TEMPERATURE. ORANGE LINE SHOWS VIBRATION ALERT LEVEL; RED LINE SHOWS VIBRATION TRIP LEVEL. | FIG. 3

UPON INVESTIGATION, SUNCOR IDENTIFIED AN **INVERSE CORRELATION** BETWEEN THE **VIBRATION AMPLITUDE** AT THE COMPRESSOR'S INBOARD BEARING AND THE **SEAL OIL INLET TEMPERATURE**

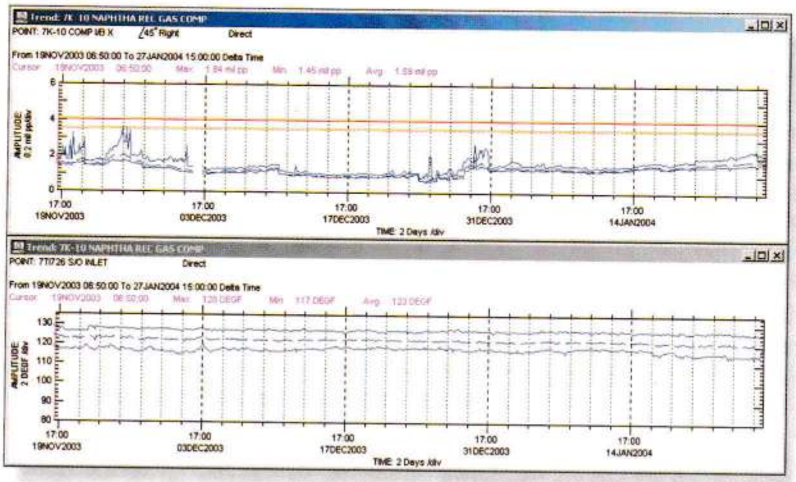
Root Cause

As a temporary fix, the control system setpoint was changed to maintain the seal oil inlet temperature between 120 and 125 deg F instead of 105 to 115 deg F. This took place at approximately 9:00 AM on October 22, 2003, and, as shown in Figure 3, had an immediate effect on the overall vibration amplitude, dropping it below alarm levels and maintaining it between 2.5 and 3.2 mils.

Over the next three months, with the new temperature setpoints established, the vibration amplitudes continued to decrease and stabilize, ranging between 1.5 and 2.2 mils as shown in Figure 4. During this time, Suncor was able to methodically investigate the root cause of the problem, which was ultimately identified as freeze-up or lack of freedom of the seal bushing, which had a direct effect on the dynamics of the rotor.

(continued on page 29)

THE ROOT CAUSE WAS ULTIMATELY IDENTIFIED AS FREEZE-UP OR LACK OF FREEDOM OF THE SEAL BUSHING



POINT: 7K-10 COMP I/B X ∠45° Right Direct

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POINT: 7TI726 S/O INLET Direct

From 19NOV2003 06:50:00 To 27JAN2004 15:00:00 Delta Time

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STABILIZED VIBRATION AMPLITUDES AS A RESULT OF TEMPERATURE SETPOINT CHANGES. | FIG. 4 •

TOTAL AVOIDED COSTS CAME TO $365,000 CDN; SUNCOR WAS ABLE TO KEEP THE MACHINE ONLINE AND WITHIN ACCEPTABLE VIBRATION LEVELS WHILE A MORE PERMANENT REMEDY WAS IDENTIFIED

System 1 Version 5.0

Small Change in Version, Big Change in Functionality

Don't let the small change in numbers fool you. System 1® software version 5.0, released in May 2004, represents substantial new functionality over its predecessor, version 4.1.

The next issue of ORBIT will provide an in-depth look at version 5.0, but if you can't wait, we encourage you to visit us online at www.bently.com for extensive information including downloadable brochures and datasheets.

Here's a partial list of what's new:

APPLICATION PACKAGES

System 1 software is now organized into Application Packages – easier to order, easier to specify, easier to apply

- **Turbomachinery** Condition Monitoring & Diagnostics.
- **Fixed and Rotating Equipment Thermodynamic Performance** – Now with performance maps, gas turbine EGT profile plots, enhanced compressor maps, and multi-variable list plots.
- **Online Balance-of-Plant** Asset Condition Monitoring & Diagnostics: Trendmaster® Pro System – Now with Acceleration Enveloping.
- **Offline Balance-of-Plant** Asset Condition Monitoring & Diagnostics: Snapshot™ Portable Data Collectors – Now with support for Snapshot™ IS and Acceleration Enveloping.
- **Hydro Turbine-Generator** Condition Monitoring & Diagnostics – Air Gap, Rotor Shape, Rotor/Stator Profile, and more hydro-specific plot types now available.
- **Wind Turbine** Condition Monitoring & Diagnostics.
- **Reciprocating Compressor** Condition Monitoring & Diagnostics.
- **Electrical Equipment** Condition Monitoring & Diagnostics – Features interfaces to digital motor, generator, and transformer protection devices such as GE Multilin™.

SYSTEM EXTENDERS

System Extenders provide additional functionality relevant to any Application Package

- **New Interfaces to Maintenance Management Software** – We now have interfaces to the SAP® R/3 Plant Maintenance (PM) Module, in addition to MRO Software's Maximo® application, allowing System 1 to trigger work orders and other actions in your EAM/CMMS software. With System 1's Decision Support functionality, work orders can contain more detailed information on the nature and causes of malfunctions, allowing personnel to perform maintenance activities more efficiently.

DECISION SUPPORT

System 1 software's powerful Decision Support℠ functionality allows it to perform automated data validation, data analysis, malfunction/event detection, and intelligent notification

- **Preconfigured RulePaks** are now available for a host of new asset types including Wind Turbines, Reciprocating Compressors, Electric Motors, and many more.
- **Decision Support Studio** – It is now easier than ever to generate your own rules, embedding your knowledge into System 1. You can also augment any RulePaks you may have installed.
- **Decision Support Studio Developer Edition** – Now you can write your own RulePaks for easier, more consistent use by broad audiences with System 1 software installed at multiple locations.

PLATFORM-WIDE ENHANCEMENTS

These enhancements are core to all System 1 applications

- **Web-enabled Display** – You can now view System 1 data and information from any computer on your network with a compatible browser* – no special display software required!
- **QuickPlot tools** – View up to four user-selected plots with a single mouse click.
- **State-qualified analysis** – Define operating states for your assets and analyze data accordingly. For example, view temperature, vibration, and flow conditions for a hydro unit only when its load is between 150 and 175MW; view cumulative time the unit operated in this load region.
- **And many more…**

To learn more, contact your nearest Bently Nevada sales professional, visit us on the world wide web, and watch for our feature-length article on System 1 version 5.0 in the next issue of ORBIT.

* Must use Microsoft® Internet Explorer 5.01 or later.

Acceleration Enveloping – Higher Sensitivity, Earlier Detection

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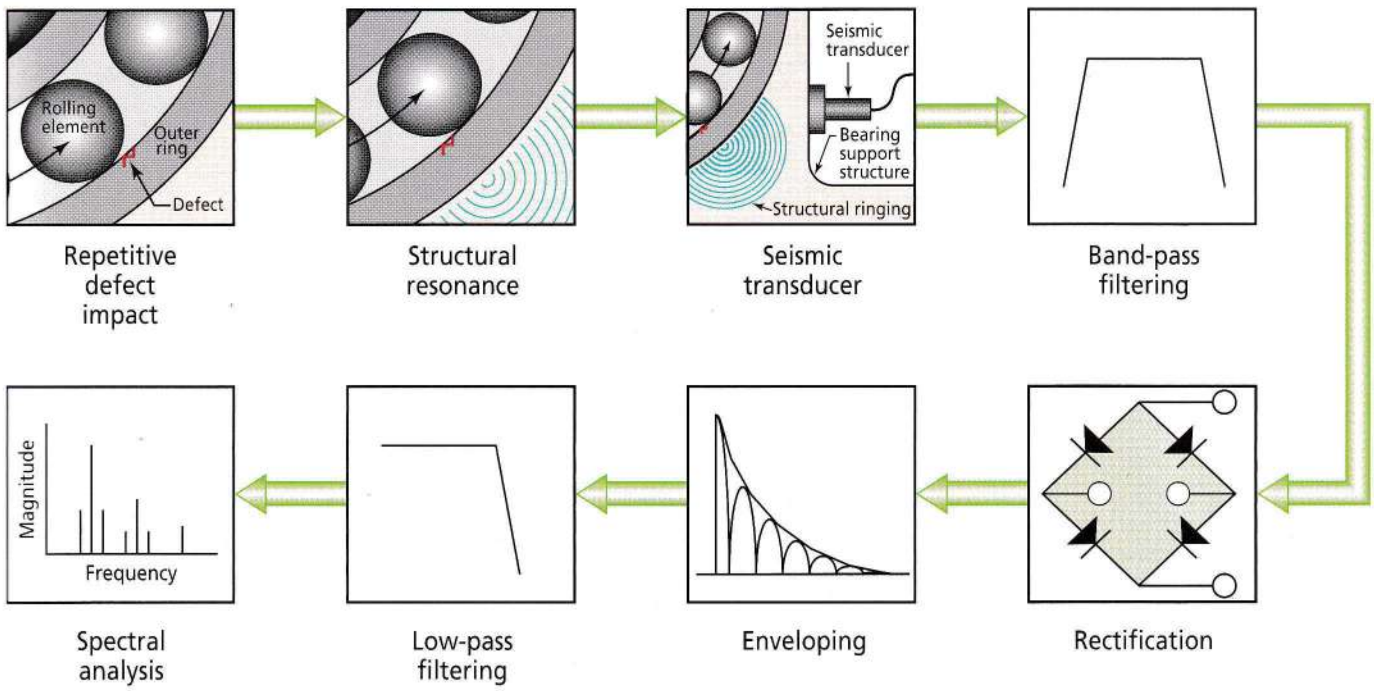
Enveloping is a tool that can give more information about the life and health of important plant assets. It is primarily used for early detection of faults in rolling element bearings and gearboxes. Enveloped acceleration is an especially valuable parameter to trend, as the progression of machine condition can be evaluated. Armed with good information and assisted by Bently Nevada service experts, plant engineers can be confident in the proper operation and management of the important assets under their care.

Enveloping can reveal faults in their earliest stages of development, before they are detectable by other machinery vibration measurements. Without an early fault detection technique like enveloping, personnel must wait until the latter stages of failure, when overall vibration increases, lubricants become contaminated, and temperatures rise. By this time, the remaining usable life of the failing machine elements could be very short and the damage more extensive than if the fault had been detected earlier.

The enveloping technique enables the detection and analysis of low-level, repetitive vibrations by extracting them from the overall machinery vibration signal. Enveloping thus facilitates earlier prediction of failure in machines with metal-to-metal contact. While the examples in this article are based on rolling element bearings, the techniques also can be applied to gearboxes and electric motors with commutators.

It is important to note that the successful application and interpretation of enveloping data require experience. Enveloping is just one tool in the analyst's toolbox, and it is best used as one of a number of techniques for complete monitoring of a machine.

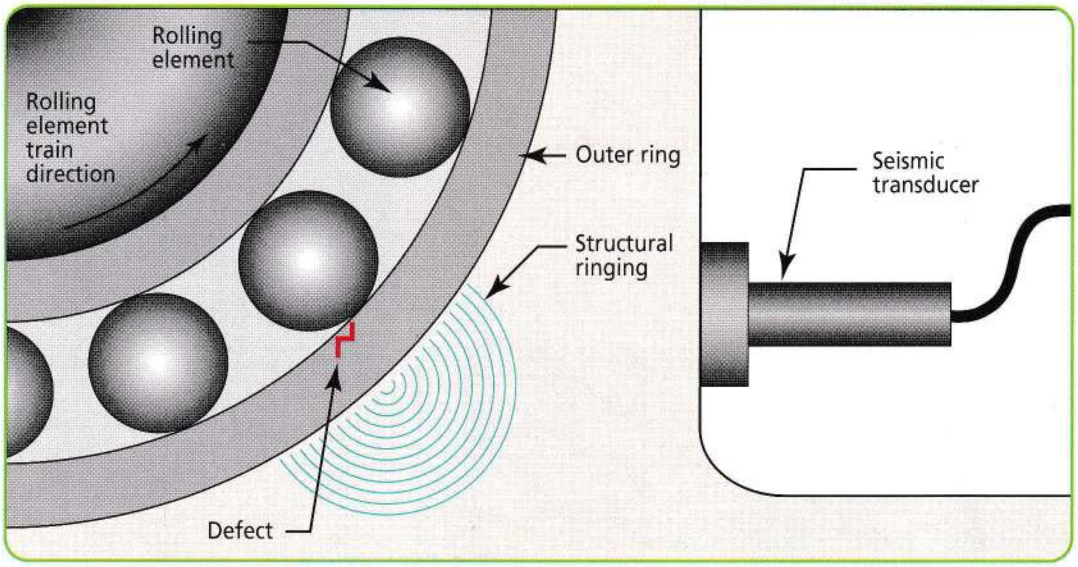


TYPICAL STEPS IN THE IMPLEMENTATION OF ENVELOPING. | FIG. 1

Enveloping Isolates Signals of Interest

Enveloping is a multiple-step process that extracts signals of interest from an overall vibration signal (Figure 1). In a rolling element bearing, the interaction between bearing elements and defects excites a structural resonance in the bearing support structure. A seismic transducer measures the vibration, and this signal is band-pass filtered to keep only signal components around the resonance frequency. The filtered signal is rectified and then enveloped, which removes the structural resonance frequency and preserves the defect impact frequency. A low-pass filter then eliminates some of the extraneous high-frequency components, and a spectrum is generated. Frequency components are correlated with physical bearing parameters, and a trend of the spectra can show progression of defects.

Analysis of the enveloping process begins with the source of the vibration signal. As the elements of



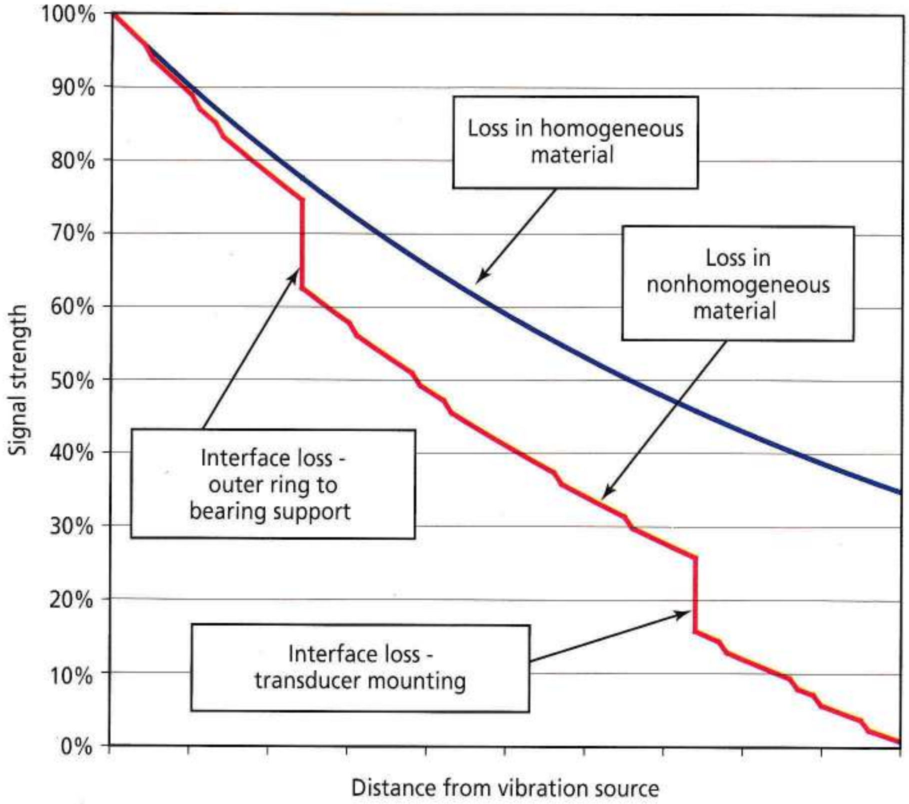
DEFECT IMPACT CAUSES RINGING OF THE MACHINE STRUCTURE AT ITS NATURAL FREQUENCIES. | FIG. 2

the bearing interact with each other and with defects, forces are coupled to the machine casing, producing vibration. These defect interactions behave as impacts that excite a natural resonance frequency of the machine, causing it to ring (Figure 2). The amplitude of the ringing decays until the next impact, which re-excites the resonance. Thus, the defect amplitude modulates the natural resonance response at the impact frequency. The defect-related signal becomes part of the overall vibration of the machine.

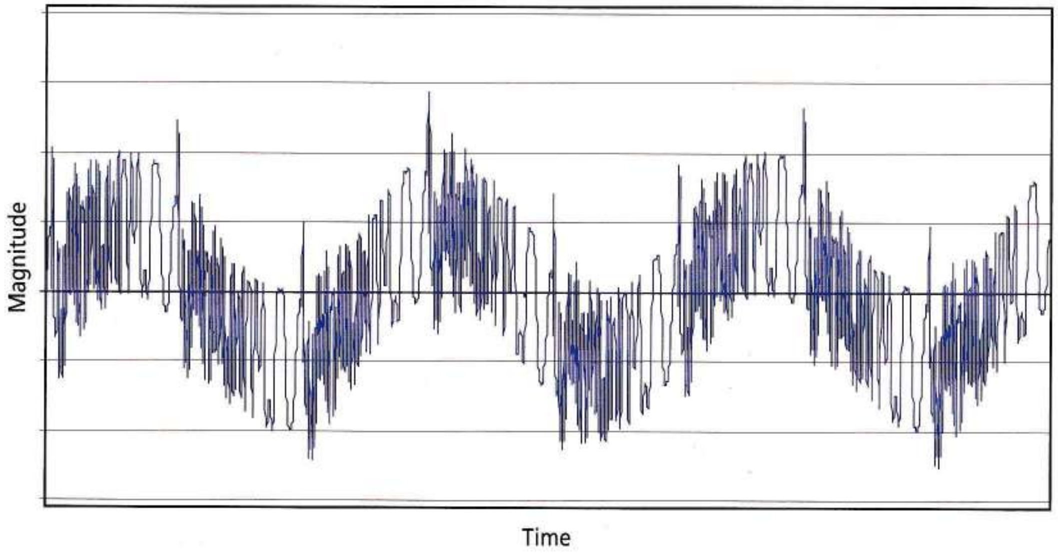
Because of its higher frequency response characteristics, an accelerometer is generally used to measure the vibration signal for enveloping. Thus, enveloping is often called acceleration enveloping or high-frequency acceleration enveloping. High-frequency vibration signals, such as the resonance carrier of the defect signal, do not travel far in a homogeneous machine structure; metal imperfections, joints, and gaskets cause further significant attenuation (Figure 3). It is critical that this low-level, high-frequency signal be coupled efficiently into the accelerometer; the accelerometer should be mounted as close to the bearing as possible and near the load region of the bearing, where signals are coupled more effectively to the machine case.

The output of the accelerometer (Figure 4) contains three important frequencies: a relatively low-frequency, high-amplitude rotor-related vibration; the modulated structural resonance frequency; and other high-frequency vibration components, including harmonics of the structural resonance frequency. Though the signal is complex, application of the enveloping technique allows us to determine an impact frequency associated with the defect, which provides valuable information about machine condition.

(continued on page 16)



VIBRATION SIGNAL TRANSMISSION LOSS IN HOMOGENEOUS AND NONHOMOGENEOUS MATERIALS. | FIG. 3



ACCELEROMETER VIBRATION WAVEFORM OUTPUT WITH EMBEDDED DEFECT SIGNAL. | FIG. 4

Implementing an Enveloping Program: What Are the Issues?

A SIDEBAR ARTICLE

While the methodology for generating an enveloping spectrum may seem straightforward, valid results depend on careful application. Consider the following eight issues before applying enveloping techniques to machinery monitoring:

1 **EARLY DETECTION:** Enveloping provides early detection of faults that would otherwise be obscured by larger components of the machine's vibration signature. However, when a fault is identified in an enveloping spectrum, failure is not necessarily imminent, but monitoring of that machinery component should be increased to trend progression of the fault. Defects will not be detectable until they have progressed to the point that their interaction with other components is repetitive, not random. Check against other data using other measurement techniques, as available.

2 **ELIGIBLE MACHINES:** Enveloping techniques can be used to detect faults in machine components with repetitive metal-to-metal interaction. However, because enveloping is not a "direct" measurement, many extraneous factors can add to or diminish the enveloped signal. Several machine components or characteristics can prevent successful enveloping implementation. Joints, interfaces, gaskets, and fluid-film or squeeze-film dampers prevent high-frequency signal transmission critical for enveloping. High-frequency operational noise may overshadow signals of interest in reciprocating machines, variable frequency drive motors, and others. Electromagnetic interference may also introduce itself into the cabling between the transducer and the signal processing device and compromise signal integrity.

3 **TRANSDUCER SELECTION:** The frequency response of the transducer must include the expected range of machine resonance frequencies (ranging from 1 kHz to more than 40 kHz). The resonance frequency of the mounted transducer must be sufficiently far away from the machine frequencies of interest to avoid interactions. The transducer should be extremely reliable to ensure trending consistency.

4 **TRANSDUCER MOUNTING:** Enveloping measurements are highly dependent on transducer mounting method and location. Even a slight change in mounting location can yield quite different results, so a solid, repeatable mounting is essential to help ensure that changes observed in data are due to changes in machine condition – not just variations introduced by the person collecting the data. A flat, clean (bare metal) surface for mounting the transducer is critical. Handheld transducer applications can be especially susceptible to variation based on changes in applied pressure, mounting angle, and other variables introduced by the person taking the reading. For this reason, use extra care when handheld transducers are used for enveloping measurements. When practical, consider affixing the transducer in a way that reduces variability such as by screwing it onto the measurement surface using a mounting stud, or – if using a handheld "stinger" assembly – develop a routine of holding it in the same manner, applying the same pressure, and orienting it at the same angle (perpendicular to the measurement surface) for every data collection location. Since the high frequency signal on which enveloping depends does not usually travel very far within a machine, the transducer mounting should have a short transmission path from the machinery component of interest, with as little damping of the high fre-

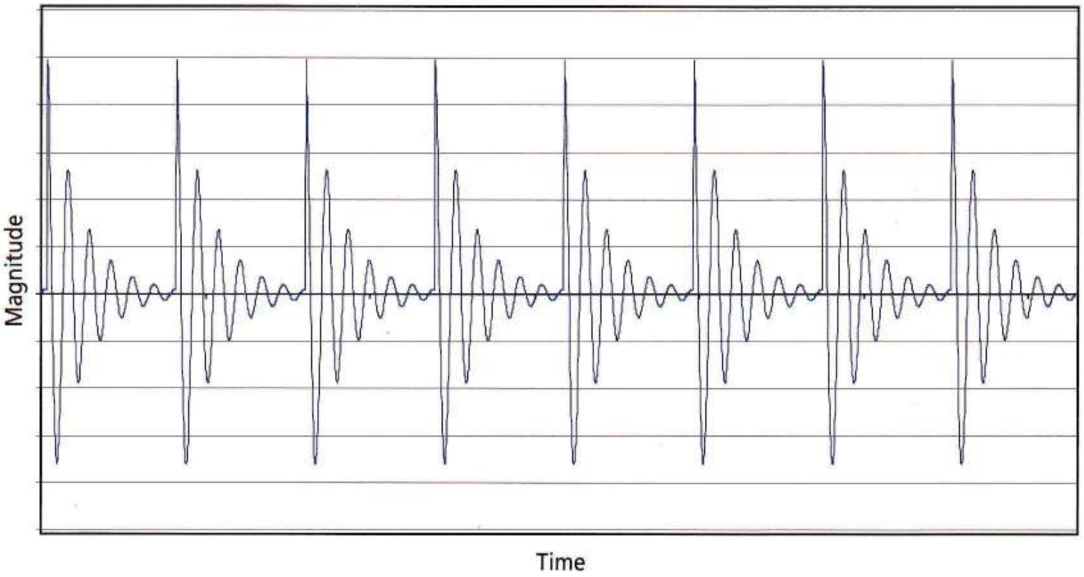
quency energy as possible. Any metal interface or discontinuity in the machine causes significant signal attenuation, and fluid films at any interface can completely stop transmission of a signal. Consequently, faults which are detected with enveloping can be expected to be located near the measurement transducer.

5 **FAULT IDENTIFICATION:** Because of the correlation between fundamental spectrum frequencies and fault sources, flawed components can often be identified before the bearing is removed and physically examined, allowing spare parts to be ordered in advance and work procedures to be written with the knowledge of precisely what needs to be changed. Frequencies associated with the machine's components and its natural resonances must both be considered when configuring the enveloping technique to ensure valid data. Since improper lubrication, caused by inadequate, excessive, or contaminated lubricants, can cause frequency components to appear in the enveloping spectrum, lubrication should be checked first when faults appear. Progression of faults is often indicated by the presence of more bearing frequency components and an overall increase in the noise floor of the enveloping spectrum. Overall, the fundamental fault frequencies in the spectrum are the most important for correlation with physical defects.

6 **SEVERITY PREDICTION:** Enveloping provides valuable information for machinery management. However, enveloping by itself does not give all the information necessary for reliable and accurate prediction of the condition of a machine component, such as a bearing or gear. In the enveloping spectrum, frequency can be correlated to a specific machine component, but increasing magnitude is not necessarily correlated to the progression of the fault. In fact, a well-known phenomenon is that the acceleration enveloping amplitude may actually decrease as bearing failure becomes more imminent. As a bearing continues to wear, its small, vibration-inducing flaws begin to smooth out, and the characteristic "ringing" caused by the flaws (and detected by enveloping) decreases. When enveloping data is used with other measurements, such as direct machine vibration, acoustical noise levels, and temperature, machinery condition can be more accurately determined.

7 **TRENDING CONSISTENCY:** Data must be collected periodically and consistently to ensure the integrity of the trend. As noted in point #4, this includes using the same transducer in the same location mounted the same way to reduce gross and systematic errors. Then the trend can be evaluated to see the progression of any defects. Permanently mounted transducers are recommended.

8 **FREQUENCY VARIATION:** The absolute frequency of enveloping signals is directly dependent on shaft rotation speed. In order for frequencies to be correlated with potential faults, machine speed must be known and relatively constant. Otherwise, the magnitude of frequency components may be affected by frequency-dependent machinery and instrumentation responses rather than changes in defect severity.



BAND-PASS FILTERED VIBRATION WAVEFORM SHOWING DEFECT MODULATION OF THE MACHINE STRUCTURAL RESONANCE. | FIG. 5

(continued from page 12)

Filtering an Important Part of Enveloping Process

Band-pass filtering is the first signal-processing step in the application of the enveloping technique. Proper filter specifications are critical to the removal of unwanted components of the signal while preventing detrimental attenuation of signal components essential for enveloping analysis. Frequency range selection must take into account machine operating speeds and structural natural frequencies, which depend, at least in part, on bearing design along with machine construction and mounting. In order to get the best (most useful) information from the enveloping technique, some experimentation with available frequency ranges for the filters is often required when enveloping is first applied.

A good starting point is to examine the spectrum plot for a high-frequency, structural resonance "haystack." The lower corner (high-pass corner) should be set above gear mesh frequencies, but below this structural resonance "haystack." The lower corner frequency is selected to reject the comparatively high-amplitude, low-frequency components that are associated with the normal machine running speed vibration. This greatly improves the signal-to-noise ratio for the frequencies of interest, since it is these lower frequencies that generally dominate the vibration signal. The upper corner frequency is selected to remove extremely high frequencies which are associated with other machine vibration frequencies and signals amplified by the accelerometer or mounting resonance.

For a machine with rolling element bearings, the lower corner frequency is generally set to be greater than ten times the running speed of the machine (10X) to eliminate the most common harmonics of running speed. However, this frequency should not exceed one-half of any structural natural frequency associated with the bearing. This natural frequency serves as the carrier frequency excited by the defect impacts, and attenuating this signal of interest is detrimental to the success of enveloping.

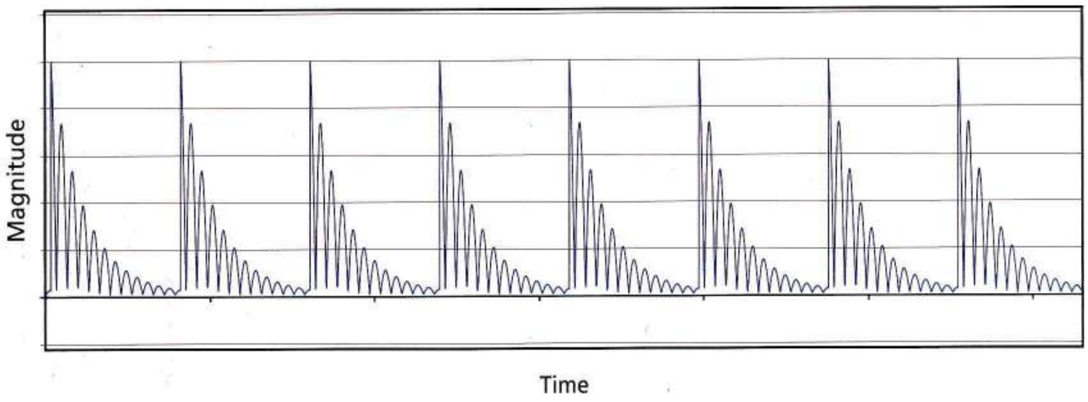
The upper corner is generally set to around sixty times the outer-race ball-pass frequency (60X BPFO), or approximately two hundred times running speed (200X). This attenuates high frequency noise and vibration components, some of which have been amplified by accelerometer resonances. These basic rules are relatively simple to apply to a rolling element bearing. However, on a gearbox they become more complicated because of gear-mesh frequencies.

The band-pass filter output (Figure 5) shows the structural resonance frequency, which is the higher frequency in the waveform, modulated by the defect. The impacts associated with the defect excite this carrier frequency, and its amplitude then decays exponentially. The signal from a defective bearing may have different impact intervals, more frequency components, and differing amplitudes – all potentially influenced by lubrication, the number of defects, the severity of the defects, and the loading of the bearing (among other things). However, enveloping is still effective and even more valuable for these more complicated signals.

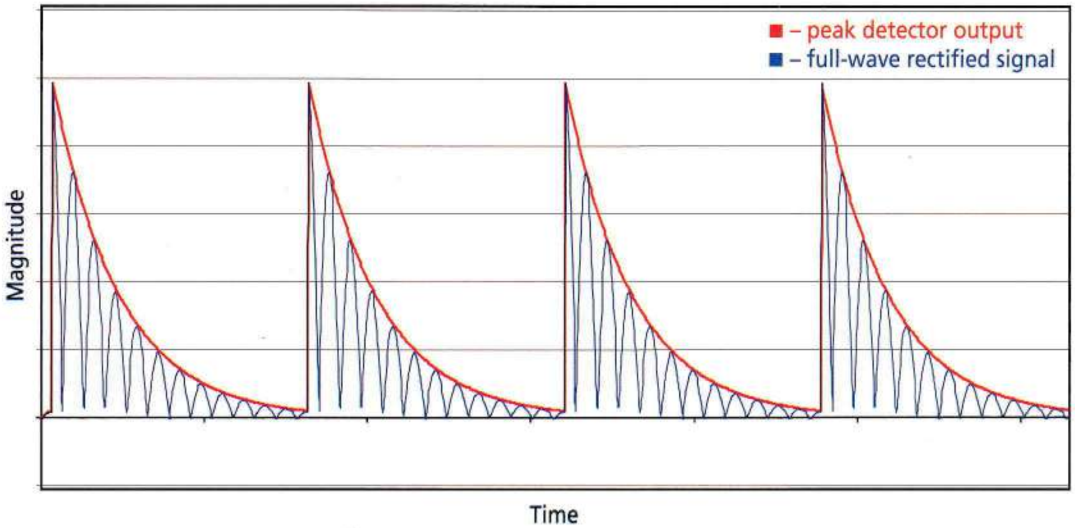
Amplitude Demodulation Eliminates the Resonance Frequency

To envelope (demodulate) the filtered signal, it first is full-wave rectified (Figure 6), which doubles the carrier frequency and further separates the impact frequency and the carrier frequency.

The next step is the actual enveloping itself. Amplitude demodulation of the rectified waveform eliminates the carrier frequency and leaves the repetition



FULL-WAVE RECTIFIED VIBRATION SIGNAL. | FIG. 6



ENVELOPE OF VIBRATION SIGNAL PRODUCED BY A PEAK DETECTOR. | FIG. 7

rate of the defect impact. A number of methods are available to accomplish demodulation, including peak detection (Figure 7), integration, and low-pass filtering.

Generally, enveloping results in a waveform which has spectral components corresponding to the defect impact frequencies and, due to the impact nature of the event, harmonics of the defect frequencies. Frequency components unrelated to the impact will generally be of higher frequency than the components of interest. Some of these can be eliminated by another application of low-pass filtering, leaving the defect impact frequencies and some low-order harmonics. Interpretation of this less-cluttered spectrum is easier, since fewer components need to be considered.

The next step before analysis is to generate a spectrum of the enveloped signal. The defect impact frequency should show up clearly in relation to all the other spectral components in the signal. Harmonics of fundamental fault frequencies are generally artifacts of the enveloping process and are not valuable for trending purposes, except that the presence of more harmonics may indicate the progression of a fault. After disregarding harmonics, significant frequencies present in the spectrum may be correlated to physical machine parameters. Note that, especially as defects become more severe, sidebands related to running speed may appear around defect frequencies in the spectrum.

If uncorrelated frequencies are present in the spectrum, the filters may have been configured incorrectly or the transducer measurements were taken improperly. Frequencies may also come from other nearby machinery components, or they may be caused by the machine operation or process. While improper measurement techniques may prevent frequencies from appearing in the spectrum, if defects are absent in the monitored machinery, then no defect-associated frequency components should be seen in the spectrum.

Interpretation of Information Is Final Step

Interpretation of the information is the very important final step. Trending the magnitude of these frequency components can indicate the progression of bearing faults, but the magnitude is not necessarily related to the severity of the defect. For example, developing faults, such as a spall, may initially cause defect frequencies that have increasingly larger amplitudes. As the spall grows, it may present less of an impact event as the edges of the fault self-peen, or smooth themselves out; the amplitudes now decrease. A measurement trend is therefore valuable to show the phases through which the signal has gone and to allow the user to infer the progression of the fault.

For trending of defect frequencies to be useful, baseline information is required. It must be taken when the bearing is known to be in good condition and often enough to provide adequate resolution of the progression of the fault. In addition, initial experimentation with filter settings will help validate data. Knowledge of the machine and its bearings is essential to identify the frequencies to monitor. Because successful trending and correlation of data requires repeatable measurements, permanently mounted transducers are recommended.

Proper Installation, Application, and Experience Make Enveloping Work

When properly applied, enveloping can be a valuable tool for early detection of faults in machines with rolling element bearings and gearboxes. It is especially useful when applied in a periodic monitoring schedule and can provide condition information indicating faults in their earliest stages of development. With the help of Bently Nevada solutions and services, including enveloping techniques, machinery availability and reliability are more certain, and personnel can be more confident of the mechanical condition of the assets under their care.

In summary, to use enveloping techniques successfully, care must be taken in a variety of areas. Experience is extremely valuable. Machinery knowledge is critical. Proper configuration of the whole measurement system is essential. Equipment selection and application must be done with all these considerations in mind, and while a good product will make the use of enveloping easier, it is never a mindless exercise. Enveloping must be used with its capabilities and limitations in mind so that, if this is done, it can be a useful tool in the hands of a capable machinery analyst.

Editor's Note: See also our article on page 58 for a case history on enveloping techniques in wind turbines.

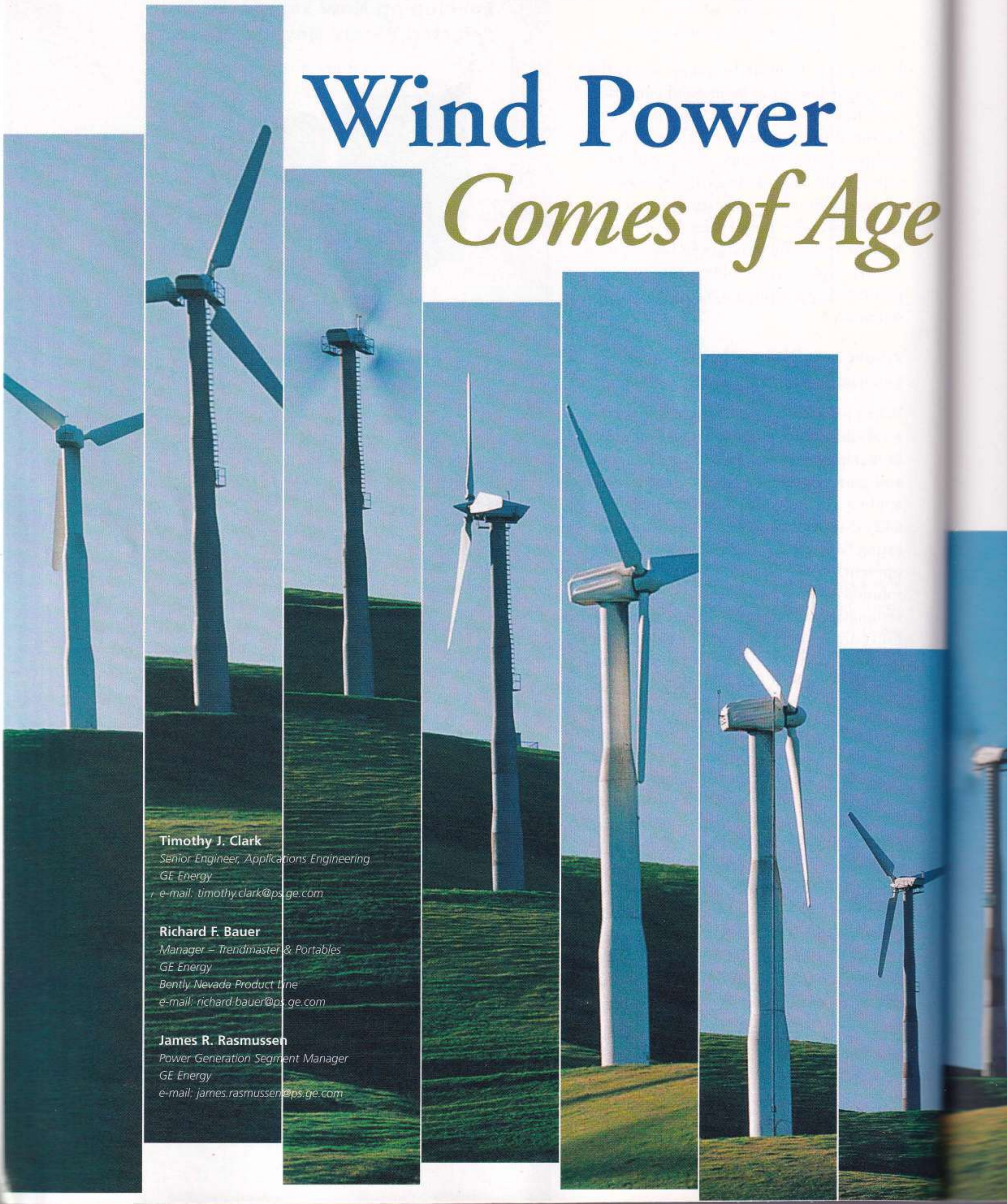
Enveloping Now Supported in Selected Bently Nevada Products

The acceleration enveloping capabilities described in this article are now available in the following Bently Nevada products:

- Snapshot™ for Windows® CE portable data collector
- Snapshot™ IS portable data collector
- Trendmaster® Pro – Dynamic Scanning Module and selected Transducer Interface Modules (TIMs)

These hardware devices can be configured to provide acceleration enveloping and other signal processing functions that are particularly useful for managing machinery with rolling element bearings. Each is supported by System 1® software where acceleration enveloping data can be displayed, archived, and trended. In addition, basic level-type alarms can be established on various aspects of the enveloped data. By adding System 1 software's Decision Support℠ capabilities, you can even configure powerful rules that embed your own intelligence and machinery knowledge to automatically analyze enveloping data, spectral data, and other machinery and process measurements (temperature, oil condition, etc.). These rules can then generate customized, Actionable Information® advisories that streamline maintenance activities by providing proactive and intelligent information, enhanced by the early warning capabilities that acceleration enveloping can provide.

Wind Power
Comes of Age



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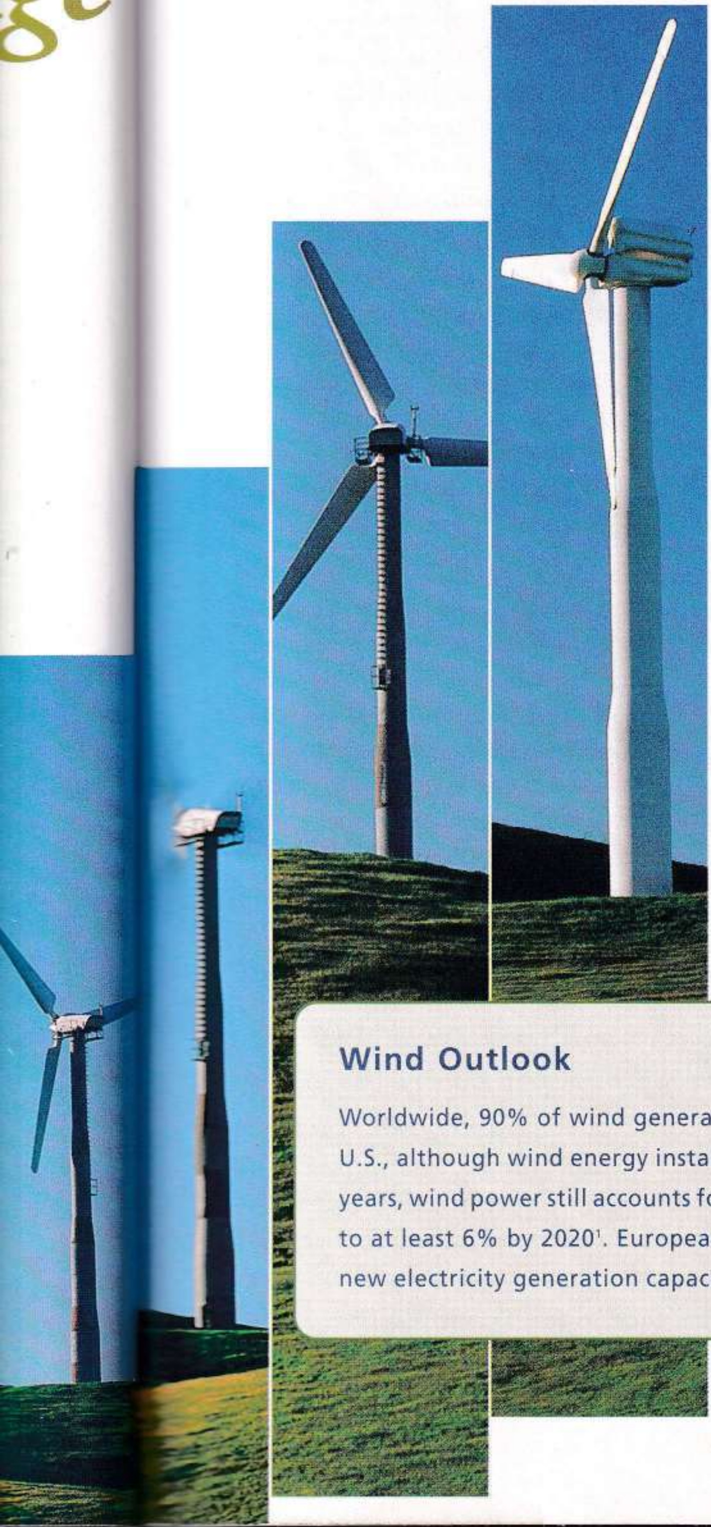


And With It, an All-New Wind Turbine Condition Monitoring System

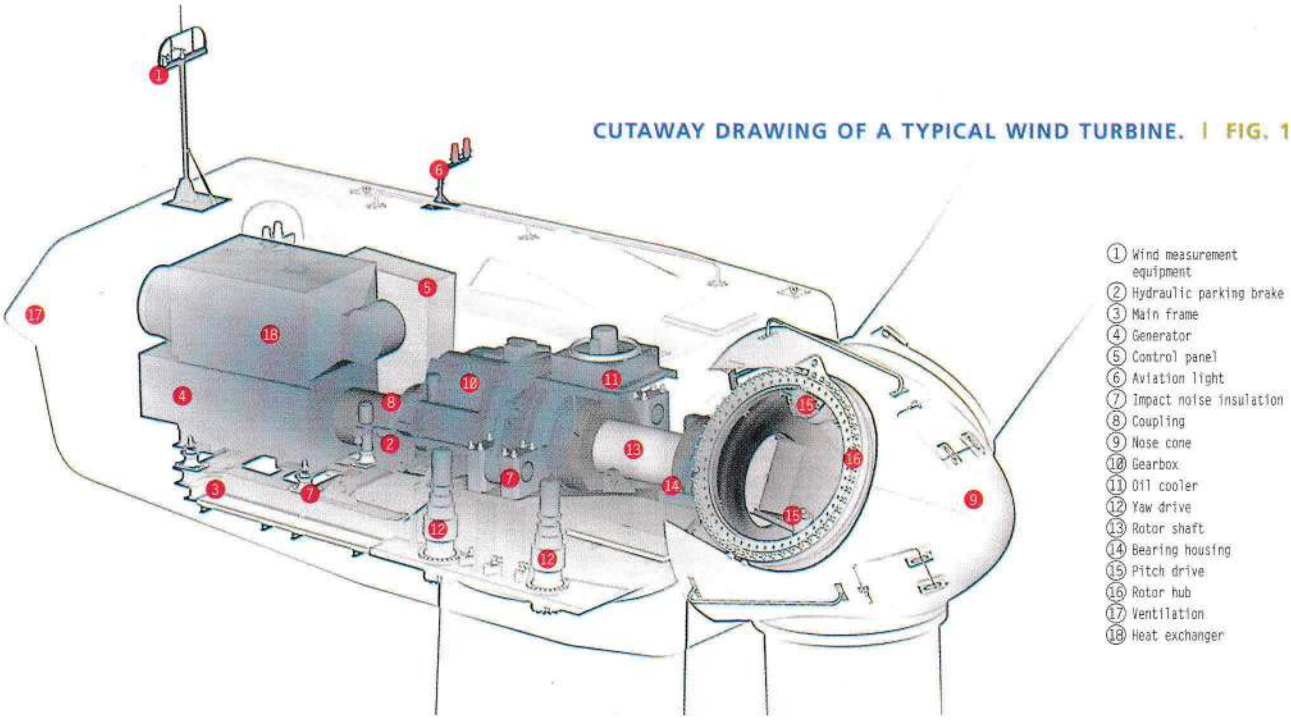
Introduction

The $9 billion US global wind energy market is experiencing dramatic growth with installed generating capacity up 500% from 7,600 MW at the end of 1997 to nearly 39,300 MW at the end of 2003. With an average annual increase approaching 32%, wind is the world's fastest growing energy source on a percentage basis, and its growth is forecast to continue a double-digit pace into the next decade[1]. While much of this growth is fueled by government decisions that are favorable to "green" or renewable power, it is also fueled by advances in wind turbine technology as evidenced by larger, more sophisticated machines. As a result, wind turbines are becoming more established as an economically viable alternative to fossil-fueled power generation. Today, wind "farms" – consisting of anywhere from a single turbine to as many as several hundred turbines – are an important component of the world's source of electric energy.

Wind Outlook

Worldwide, 90% of wind generation capacity is split between Europe (75%) and the U.S. (15%). In the U.S., although wind energy installations have grown at an average rate of nearly 25% over the past five years, wind power still accounts for less than 1% of U.S.-generated electricity. However, this could increase to at least 6% by 2020[1]. European targets for wind power are substantial – wind will deliver 33% of all new electricity generation capacity and provide electricity for 86 million Europeans by 2010[2].

CUTAWAY DRAWING OF A TYPICAL WIND TURBINE. | FIG. 1



The Wind Turbine

Most modern wind turbine drivetrains consist of a three-blade turbine that operates at low speed, usually between 10 and 20 RPM, and has adjustable blade pitch, allowing the control system to "feather" the blades to accommodate varying wind conditions. Shaft speed is increased through a gearbox to approximately 1,000 to 2,000 RPM to turn a four- or six-pole generator. All of the wind turbine drivetrain bearings are of the rolling element type. The drivetrain is mounted on top of a tower in a nacelle along with the turbine's control system. This tower is hollow, with an access ladder inside leading up to the nacelle. Wind turbines also include atmospheric sensors on top of the nacelle to detect wind speed, wind direction, and other parameters, and these are connected to the control system. By sensing wind direction, the control system uses a yaw motor on top of the tower to pivot the nacelle so the turbine faces the wind. Typically, all of the wind turbines in a farm will have their own local area network, linking their SCADA, control, and other instrumentation systems to one another and to a local or remote operations center.

The Business Case

Until the last few years, most wind turbines were less than 1 MW in size and the economics of monitoring these machines would rarely support a continuous condition monitoring system. Unlike large, critical turbo machinery where the ability to reduce downtime (often millions in lost revenue per day) is generally the primary incentive for a continuous condition monitoring system, this is not the case for wind turbines. Even though the size of wind turbines has steadily increased (the average size of wind turbines in 2003 was about 1.5MW with 3+ MW machines currently available and 5+ MW machines in beta testing), it is the high cost of maintenance – not downtime – that provides the primary justification for an online condition monitoring system.

Drivetrain maintenance – primarily related to gearbox and bearing problems – is the number one cause of extended outages on wind turbines. In most cases, the gearbox and bearings degrade slowly with operating time. During this slow degradation process, the components provide characteristic failure vibration signatures that can be detected if the user knows what to look for.

Proud to be Allianz-Certified **Allianz**

Allianz, a prominent global insurance and financial services company, is leading efforts in Europe to certify condition monitoring systems for wind turbines. By installing a certified condition monitoring system, wind turbine operators can avoid insurer-mandated overhauls every 40,000 operating hours or five years, whichever comes first. The Bently Nevada monitoring system described in this article received Allianz certification in April, 2004.

The ability to detect failures is important because bearing and gear wear, if not caught in time, will often progress to more serious collateral damage affecting the other parts of the drivetrain and the generator. This necessitates far more costly repairs than simply replacing a bearing or gear at the end of its useful life. When a $1,500 bearing fails unnoticed, it can lead to a $100,000 gearbox replacement, a $50,000 generator rewind, and a $70,000 crane to access the failed components (and even more expense if it is an offshore location). Without some method of detecting the machine's condition, these scenarios can and do occur.

Recognizing this, insurers in Europe are now requiring turbine overhauls every 40,000 operating hours *unless* the turbine is instrumented with a certified monitoring system (see sidebar). Thus, monitoring systems today have favorable impact on not only maintenance costs, but on alleviating mandated outages as well.

The Need for Online Monitoring

Many operators simply run their wind turbines to failure and then repair them. However, as noted above, run-to-failure is becoming a less-viable option as machine sizes increase, drivetrains become more costly, and insurer-mandated outages influence operating and maintenance economics. In addition, these machines are – by design – located in windy locations that are often remote and difficult to access. Many repairs require a crane, but safety concerns preclude using a crane when wind velocities are high. Thus, a 2-day repair may require many more days of lost production because users must wait for favorable weather conditions in which to conduct repairs.

Other wind turbine end users have implemented periodic surveillance with hand-held data collectors. However, this approach has several drawbacks.

DRAWBACKS of Portable Data Collection

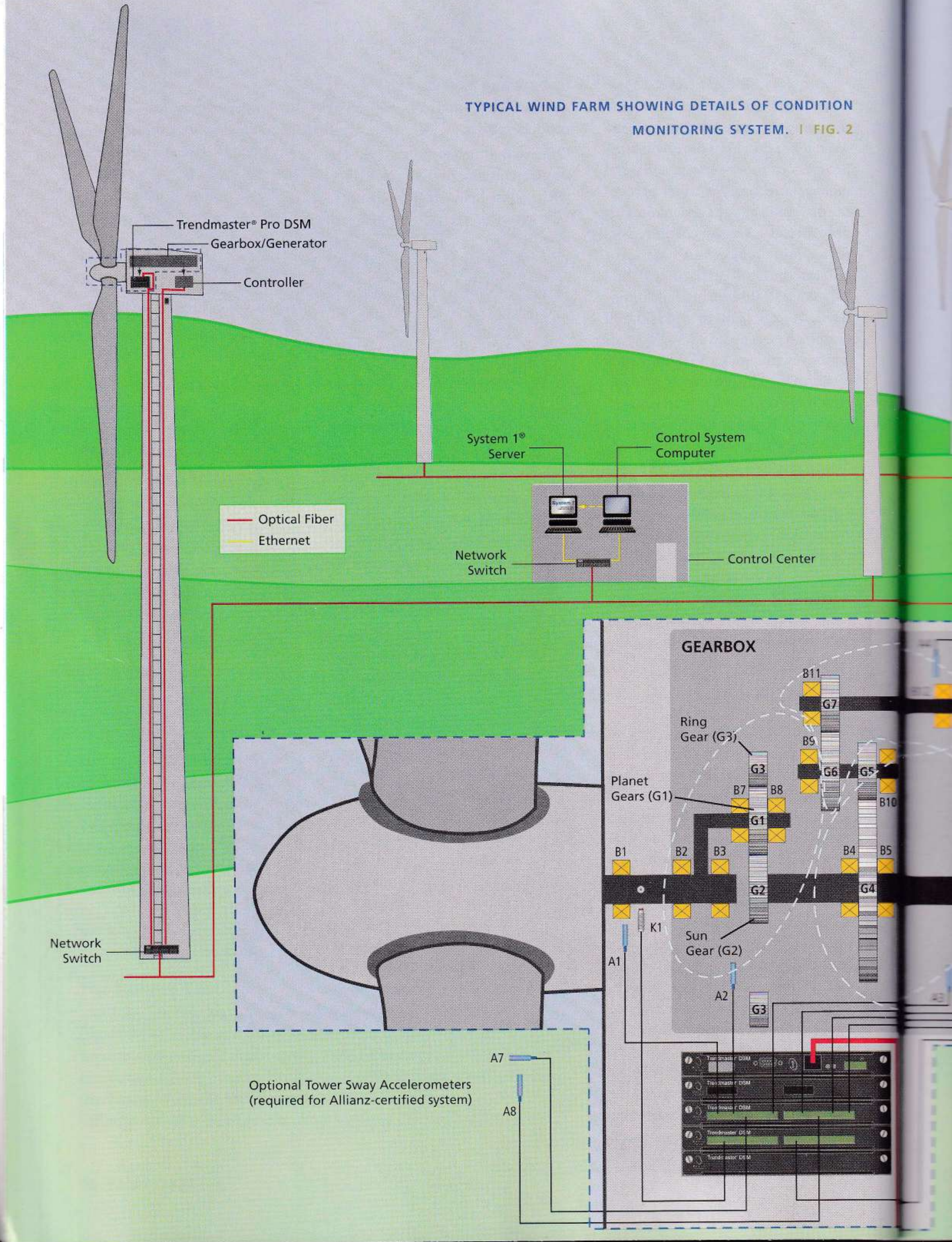
- It is impractical for remote locations – travel costs become excessive.
- It poses safety concerns; personnel must climb the tower to the inside of the nacelle, taking measurements while the machinery is operating.
- Vibration data on wind turbine drivetrains varies with wind velocity, machine RPM, and power (torque) output; manual data collection cannot easily ensure that data will be collected under consistent conditions, making data analysis difficult if these variables are not known.
- Variation in hand-held transducer placement, orientation, pressure, and other factors can introduce significant variation in readings.
- Collecting data from wind turbines generally requires at least two people, to comply with company safety policies. In addition, personnel can generally only survey four to five wind turbines per day because of the strenuous climbing involved. A conventional manual data collection program runs around 0.2 to 0.3 man-hours per machine each time data is collected. In contrast, a wind turbine conservatively requires at least 3.2 man-hours per machine, making it a minimum of ten times more expensive to manually collect data than in other industries.

In contrast to run-to-failure and portable data collection strategies, an online system provides numerous benefits for users.

BENEFITS of Continuous Monitoring

- Labor costs are reduced because personnel aren't traveling to collect data.
- Failures between data collection intervals are far less likely because data is collected every few minutes rather than weeks or months.
- Personnel are not put in hazardous situations – data can be monitored remotely without climbing towers or even traveling to site.
- Mandated outages by insurers can be waived; maintenance can be based on observed condition rather than operating hours.
- Data can be more easily correlated with operating variables from SCADA and control systems, providing a more comprehensive look at the machine.
- Data can be collected when machine conditions, such as power (torque), shaft speed, and wind velocity are similar, allowing normalization of data for more consistent and effective machinery diagnostic decisions.

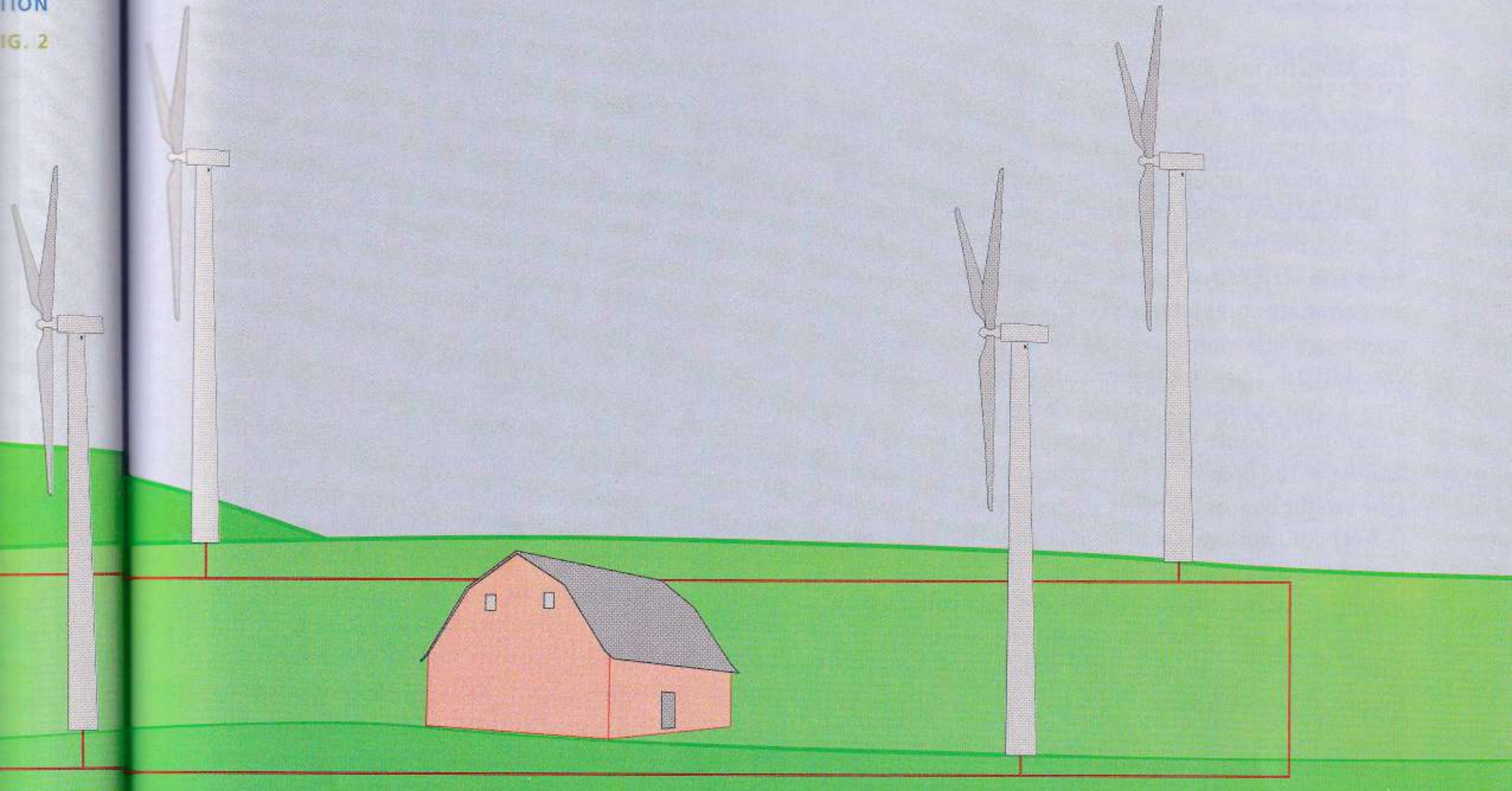
(continued on page 26)

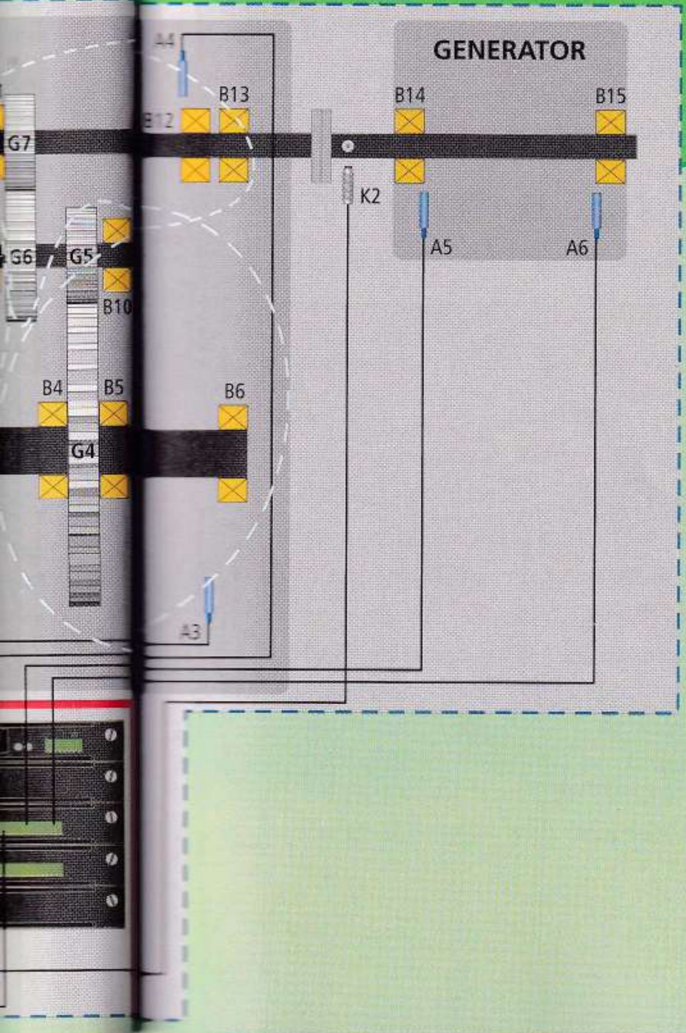


TYPICAL WIND FARM SHOWING DETAILS OF CONDITION MONITORING SYSTEM. | FIG. 2

TION

IG. 2





ID	Sensor	Component(s) Monitored	Required Measurement?
A1	Main bearing accelerometer	Turbine main bearing (B1)	Yes
A2	Planetary gear stage accelerometer	Planetary gears/bearings (G1, G2, G3, B2, B3, B7, B8, B9)	Yes
A3	Intermediate speed stage accelerometer	Intermediate-speed gears/bearings (G4, G5, B4, B5, B6, B10)	Yes
A4	High speed stage accelerometer	High-speed gears/bearings (G6, G7, B11, B12, B13)	Yes
A5	Generator inboard accelerometer	Generator inboard bearing (B14)	Yes
A6	Generator outboard accelerometer	Generator outboard bearing (B15)	Yes
A7	Nacelle transverse accelerometer	Tower sway perpendicular to turbine shaft axis	No, but highly recommended. (Required for Allianz-certified system.)
A8	Nacelle axial accelerometer	Tower sway parallel to turbine shaft axis	No, but highly recommended. (Required for Allianz-certified system.)
K1	Keyphasor® 1	Turbine speed	Yes
K2	Keyphasor® 2	Generator speed	Yes
V1	–	Power	Yes – obtained from SCADA or control system and imported to System 1 software.
V2	–	Torque	Yes – obtained from SCADA or control system and imported to System 1 software.
V3	–	Wind velocity	Yes – obtained from SCADA or control system and imported to System 1 software.

(continued from page 23)

The Monitoring System

Bently Nevada now has a condition monitoring solution specifically for wind turbine drivetrains. Based on our proven Trendmaster® Pro platform that is now in its third generation (see our feature-length article on page 30), the system uses strategically placed accelerometers and Keyphasor® phase reference transducers on the drivetrain components in conjunction with a signal processing technique known as acceleration enveloping (see sidebar). These transducers are connected to a dedicated data collection device, known as a Dynamic Scanning Module (DSM) mounted in the control cabinet in the nacelle. A fiber optic cable runs from the DSM to the base of the tower where a local area network (LAN) connection is available. The LAN is also connected to a computer running System 1® condition monitoring software, which analyzes the data collected by each DSM and provides intelligent alarming and advisory messages to operations and maintenance personnel. Figure 2 on pages 25-26 summarizes the system.

Consistent Measurements

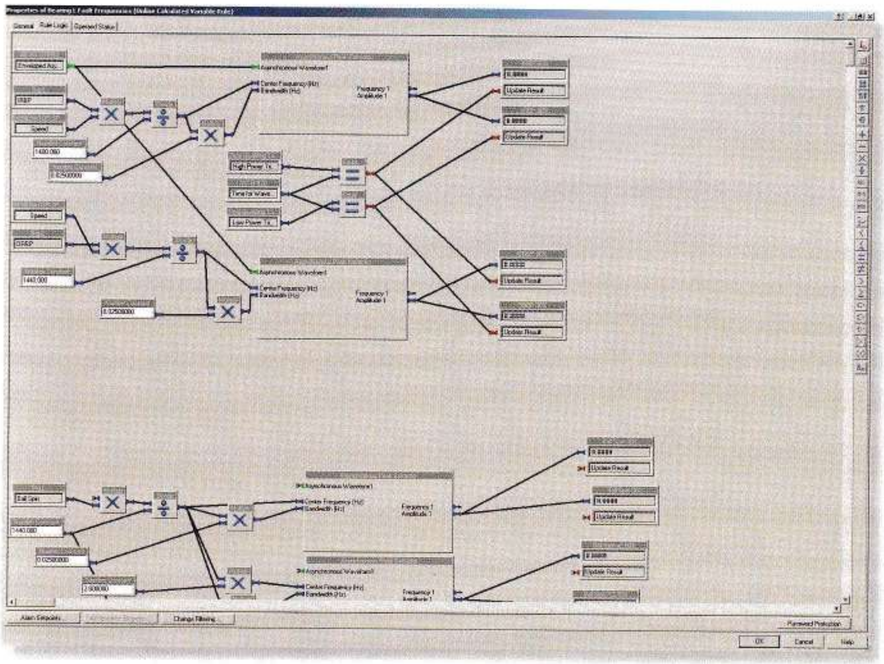
Special care has been taken in the design of the system to collect vibration data under all operating conditions while also including variables (such as power and speed) that represent the machine's operating state. Vibration data is known to vary widely with turbine operating speed and power output. By collecting supplementary operating state data, analysis and diagnostic conclusions can be drawn more consistently. It also allows alarm setpoints to be established more effectively, since alarms can now be a function of operating states.

Proven Results

The system described above has been installed on critical wind turbines for over a year, successfully logging nearly 60,000 turbine-hours of operation. During that time, Bently Nevada has not only proven that the system can reliably detect drivetrain problems, we have also developed a corresponding methodology for diagnosing these machines and embedded this knowledge into a special set of rules (called a RulePak) for System 1 software, the application used for viewing, analyzing, and diagnosing condition-related data. As noted in the sidebar on acceleration enveloping, a wind turbine drivetrain represents numerous condition monitoring complexities, and automated analysis and diagnostics are a key need for wind turbine operators. The Wind Turbine RulePak enables this capability, allowing System 1 software to automatically analyze the data collected by the monitoring system and generate intelligent, plain-language advisories for operations and maintenance personnel, promptly notifying them of machinery problems and providing corrective action recommendations.

Acceleration Enveloping

A wind turbine's drivetrain poses unique challenges for monitoring. The gearbox generally employs a planetary first stage and one or two other conventional stages, utilizing six or more gears and giving rise to numerous gear meshing frequencies. Also, the gearbox, main turbine, and generator may collectively account for 15 or more rolling element bearings, all with characteristic vibration frequencies based on their geometries. The result is a very complex collection of vibration amplitudes and frequencies, all of which must be interpreted properly to understand the machine's condition. To assist in deciphering this information, our wind turbine diagnostic and detection methodology relies heavily on a signal processing technique known as acceleration enveloping. You can read more about the effectiveness of this technique in our companion articles on pages 10 and 58 in this issue of ORBIT.



CONVEYING THE DIAGNOSTIC COMPLEXITY OF WIND TURBINE DRIVETRAINS, SHOWN HERE IS A PORTION OF THE RULE LOGIC USED TO EXTRACT BEARING DIAGNOSTIC INFORMATION FOR INNER RACE BALL PASS (IRBP) AND OUTER RACE BALL PASS (ORBP) FREQUENCIES. | FIG. 3

For New and Retrofit Applications

This new monitoring system can be retrofit to existing machines, or, when specified by customers, installed at the factory on new units. The hardware as well as the embedded intelligence in the software's Wind RulePak are designed for use on any wind turbine, regardless of manufacturer. Whether you are an end user of wind turbines, or an original equipment manufacturer, we encourage you to contact your nearest Bently Nevada sales professional to learn more or visit us on the Web at www.bently.com.

1. American Wind Energy Association
2. European Wind Energy Association

ANNOUNCEMENT

New Wind Turbine Monitoring System Destined for 14 Machines in China

An order for Bently Nevada's new wind turbine monitoring system was received in May, 2004, for two wind farm projects currently underway near Shanghai, China.

Together, the two farms comprise fourteen 1.5MW turbines, and each machine will be fitted with an Allianz-certified version of the monitoring system described on page 20 in this issue of ORBIT. A total of eight accelerometers will be installed on the drivetrain and generator bearings of each machine to collect vibration data indicative of machinery health, and a fiber-optic network will link the turbines into System 1® software, providing an integrated condition monitoring system for each wind farm. The software features a specially designed RulePak with embedded knowledge for automatically analyzing the collected data and identifying malfunctions relevant to wind turbines, allowing intelligent notification of mechanical conditions requiring attention.

Bently Nevada is also working closely with the end user and the turbine OEM to determine the specific bi-directional communication features that will be implemented between the condition monitoring system and other control/automation systems used in the project, allowing comprehensive operating and condition information for both operators and maintenance personnel.

The wind farm projects are both slated for completion in May, 2005, and are subject to World Bank financing approval, which is currently pending.

3500/63 Gas Detection Monitor

A logical addition to your machinery protection platform

Hazardous Gas Detection – A Critical Measurement

Many of the machines being monitored by Bently Nevada's 3500 Systems compress, pump, or use as fuel, combustible gases. Often, these machines are located in confined or enclosed spaces where, if a leak occurs, these gases can accumulate and reach potentially explosive or asphyxiating concentrations. In many cases, the control panel housing the Bently Nevada machinery protection system will also contain a separate monitoring system for detecting the presence of these hazardous gases. Since both of these systems must continuously monitor critical parameters, they share many common properties such as robust self-checking capabilities, standard or optional redundancy, and high-integrity alarming capabilities, to name a few.

Integrated Protection

Increasingly, customers have expressed the need to simplify their instrumentation installations for improved reliability, reduced installation costs and wiring complexity, reduced maintenance requirements, and reduced control console size. Those who package machinery are likewise looking for ways to reduce design/installation costs and complexity in the instrumentation they offer to end users. A common theme is the request to integrate similar measurements and protective functions into a single platform, particularly those associated with turbomachinery such as overspeed detection and hazardous gas detection, while maintaining the necessary integrity for each individual measurement.

The 3500/63

To address these customer needs, Bently Nevada has developed the 3500/63 module for monitoring hazardous gas concentrations, augmenting the machinery protection and overspeed detection capabilities already present in 3500. Customers can now turn to a single supplier for these high-integrity measurements, combining them in the same rack if desired, or segregating them into separate racks when maximum independence is needed.

The new 3500/63 module is a 6-channel monitor occupying a single 3500 rack slot, accepting inputs

Our new 3500/63 Gas Detection Monitor is particularly well-suited for pipeline compressor stations.

from industry-standard heated catalytic-bead type sensors (hydrogen and methane). It indicates gas concentration as a percentage of the Lower Explosive Level (LEL) for the gas, and can be utilized in either a simplex or redundant (TMR) 3500 rack configuration. Each channel provides two levels of user-configurable alarms, and 4-20 mA outputs are provided for analog connection to strip chart recorders and other instrumentation. The 3500/63 is compatible with all standard 3500 capabilities such as digital interfaces via the communications gateway module, complex voting logic and external alarm annunciation via the 3500/32, 3500/33, and 3500/34 relay modules, connectivity to System 1 software via the 3500/22M rack interface module, and many others.

Applications

While there are many different opportunities to apply the 3500/63, spanning numerous industries and machine types, one particularly important application is on compressors used in natural gas pipelines. Due to their high efficiency and their ability to use the product flowing through the pipeline as fuel, gas turbines are the prime mover of choice for pipeline booster compressors. Natural gas is thus present both in the gas turbines as fuel and in the compressors as a working fluid. Often mounted in enclosed buildings, gas can leak from these machine trains under a variety of conditions. Consequently, hazardous gas detection is a standard part of a compressor station's instrumentation to ensure safety in these confined spaces. The 3500 platform can now conveniently provide such measurements in a single, high-integrity rack, reducing the wiring, physical mounting space, and integration requirements of separate systems.

For additional information on this new module, visit us on the Web at www.bently.com, or contact your nearest Bently Nevada sales professional.

Suncor (continued from page 8)

Epilogue

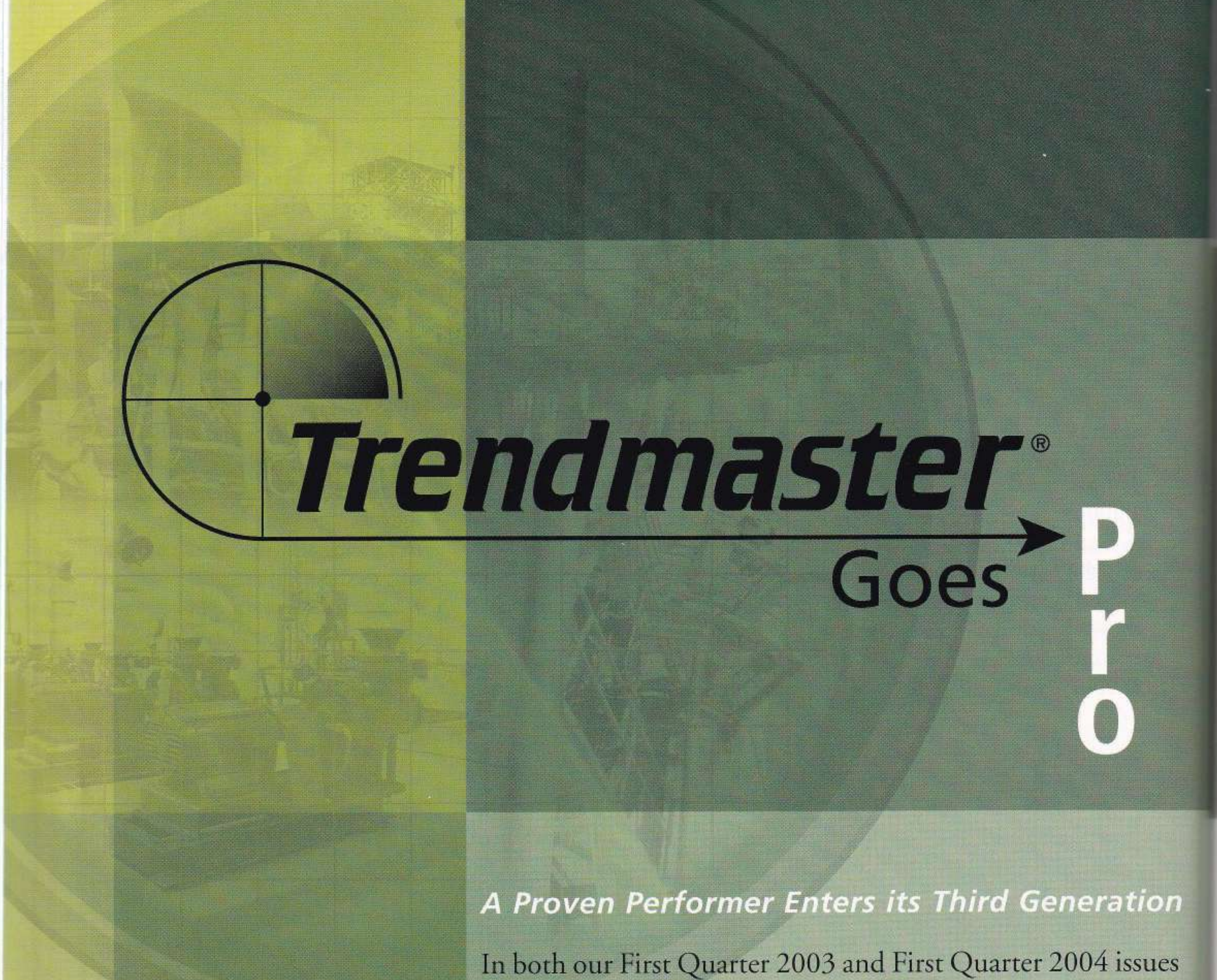
By virtue of a simple setpoint change to the seal oil inlet temperature, an unplanned unit shutdown with an estimated duration of 72 hours had been avoided. Total avoided costs came to $365,000 CDN ($300,000 in lost production and $65,000 in maintenance expenditures). Suncor was able to keep the machine online and within acceptable vibration levels while a more permanent remedy was identified. They are now developing a project to modify and upgrade the seal design, and also to overcome several existing limitations in the lube and seal oil systems.

The correlation capabilities of DM2000 proved indispensable in diagnosing this particular problem. They allowed Suncor to quickly identify the relationship between two independent parameters that might never have been noticed had they not integrated condition and process data into the same system. Once the correlation between the seal oil temperature and the vibration amplitude was established, the recommendation for a proposed solution followed through as a logical result. The solution was quick, effective, and allowed Suncor to continue operations while the permanent root cause was addressed. And, DM2000 helped Suncor narrow their root cause investigation to the sealing and lubrication components of the machine, saving time and money.

Summary

As demonstrated in Parts 1 and 2 of this article, Suncor's Upgrading Operations are using the DM2000 system to manage their critical rotating machinery more effectively, reducing both downtime and repair costs. Suncor is very pleased with both the system and Bently Nevada's turnkey project capabilities that were used to install the system for them back in 1999.

Payback from the system has been so favorable that Suncor is currently looking towards further enhancements. Projects to include additional machinery from the newer areas of Upgrading under the CVMP are under consideration.



Trendmaster® Goes Pro

A Proven Performer Enters its Third Generation

In both our First Quarter 2003 and First Quarter 2004 issues of ORBIT, we provided brief overviews of the new capabilities and enhancements being added to our Trendmaster® System. We also promised a more in-depth look in an upcoming issue of ORBIT.

Here, we provide that as-promised look at Trendmaster Pro – the latest generation of our Trendmaster System. We also provide an overview for those not familiar with the Trendmaster platform.

***Trendmaster* Timeline**

Year	Product	Platform
1989	*Trendmaster® 2000*	*Stand-alone / DOS*
1994	*Trendmaster® 2000 for Windows®*	*Stand-alone / Windows® NT*
2003	*Trendmaster® Pro*	*System 1® / Windows® 2000*

If you happen to be an existing Trendmaster user or are already familiar with the system, you may wish to simply read the sidebar at right and then jump ahead to the "Trendmaster Architecture" section beginning on page 35. If, however, you would benefit from a quick tutorial on what Trendmaster does and where it fits in the overall scheme of your condition monitoring strategy, keep reading here.

Asset Categories

All equipment assets are not created equal. Some – such as large, un-spared process compressors – have the entire plant process stream flowing through them, and represent enormous lost production costs when they don't run. Others, such as the hundreds of small pumps, motors, blowers, fans, fixed equipment and other assets that populate a typical plant, are spared or have a minor impact on plant output when they fail, but represent appreciable collective maintenance costs and can benefit from some form of condition monitoring. Still other assets simply don't merit much more than a "tighten the bolts, change the oil" approach without any routine condition monitoring. And finally, there is that class of assets that falls somewhere in the middle – benefiting from continuous monitoring, requiring more than intermittent manually gathered data, but not able to justify the expense of monitoring system architectures typically applied only to the most critical equipment assets.

Table 1 summarizes the four broad asset categories most frequently used by customers when considering the type of condition monitoring to apply.

Trendmaster® Pro – What are the major changes from Trendmaster® 2000 for Windows®?

- ***Dynamic Scanning Modules***

  Signal Processing Adapter (SPA) cards no longer reside in the host computer, and instead reside in an external mini-rack known as a Dynamic Scanning Module (DSM). The DSM connects to the host computer using conventional wired or wireless Ethernet. This provides more installation flexibility, compatibility with a greater variety of computers, and better options for reducing installation and wiring costs. The new DSM also provides numerous capabilities beyond those of the older embedded SPA cards, such as the ability to directly wire points into the system without the requirement for a Transducer Interface Module (TIM) (see page 43).

- ***System 1® Compatibility***

  Previously, the Trendmaster system used stand-alone Trendmaster® 2000 software. Today, we've integrated the support for Trendmaster data acquisition hardware into the System 1 platform, where it provides a common software environment for all equipment data, whether collected from a 3500 rack, portable data collector, or Trendmaster hardware.

- ***New TIMs and Transducers***

  While our new Trendmaster Pro system is backwards compatible with all previous generations of TIMs, transducers, and cabling, we have recently introduced several new transducers and TIMs, providing increased functionality, easier configuration, more mounting options, and ATEX approvals.

- ***Acceleration Enveloping***

  Selected TIMs and DSM Direct Input Cards now support acceleration enveloping. This enhanced signal processing can provide earlier warning of impending failures on rolling element bearings, gearboxes, and other machine elements. See our feature-length article on page 10 for more information.

OVER THE PAST 10-15 YEARS, THOSE ASSETS THAT FALL INTO THE TIER 2 CATEGORY HAVE BEEN AN INCREASING SOURCE OF CONCERN TO OUR CUSTOMERS

TABLE 1

Category	Description	Economics		Recommended Monitoring Technology
Tier 1 "Critical"	Equipment assets that have large or total impact on plant output; equipment that represents significant repair costs; equipment that has significant safety ramifications if failure occurs. Failures can occur very suddenly and may not always give advance warning.	Failures are very expensive – often millions of dollars per day or event, due to lost production, environmental impact, or health and safety impact. Typical examples include large horsepower, large energy density machines with very large replacement and maintenance costs. Financial justification for monitoring these assets comprises lost production avoidance, reduced maintenance costs, and protection of life and environment.	Method	Continuous, non-scanning (3500, 3300,1701, etc.)
			Type	Protection and condition monitoring
Tier 2 "Essential"	Equipment assets that have lesser impact on plant output; equipment with moderate repair costs; equipment that can have health- and safety-related implications if failure occurs. Failures can occur relatively quickly (minutes or hours), but usually with some advance warning.	Similar to economics of critical equipment assets, but of smaller magnitude. Typical examples include medium horsepower machines with moderate replacement and maintenance costs. Financial justification for monitoring these assets comprises the same factors as critical equipment, but usually of smaller magnitude.	Method	Continuous, scanning (Trendmaster® Pro)
			Type	Condition monitoring only (no protection*)
Tier 3 "General Purpose"	Equipment assets with little or no direct impact on plant output; equipment that represents limited repair costs; equipment that has minor safety ramifications if failure occurs. Failures generally occur with weeks or months of advance warning.	These typically include smaller assets, with small individual replacement and repair costs, and little or no costs related to lost production. However, due to the large number of such assets in many plants, they collectively comprise a large percentage of the annual maintenance costs and the financial justification for condition monitoring relies primarily on reducing maintenance costs.	Method	Manual data collection (Snapshot™ family of portable instruments)
			Type	Condition monitoring only (no protection)
Tier 4	Equipment that is not related to the process in any fashion and has no direct impact on plant performance.	Similar to Tier 3, but even less important equipment assets with small individual replacement and repair costs, and no costs related to lost production. The ramifications and costs of failure do not exceed the costs to monitor (or have excessive payback periods), and a run-to-failure or planned maintenance (rather than predictive maintenance) approach is deemed the most cost-effective.	Method	None
			Type	None

** A relatively small number of Tier 2 assets may benefit from basic machinery protection as well. Bently Nevada provides our 1900 series monitors for use in such circumstances. These small, stand-alone devices provide basic continuous machinery protection capabilities and are appropriate for machines where only one, or a few, measurement points can adequately address the asset's protection requirements. 1900 series monitors include an option for direct interface to a Trendmaster® Pro system.*

While these categories incur different names by different customers, and may have slightly differing attributes, we have found that a classification system with four tiers is the most common. We have also found that the decision regarding the particular category to which an asset should be assigned will vary from customer to customer. However, variation usually occurs in the middle categories rather than at the extreme ends. The assets that are critical are generally readily apparent to operations, maintenance, and plant management alike. Likewise, the assets that are simply too unimportant to merit any kind of condition monitoring program are often readily apparent. It is the continuum of assets between these two extremes that can be most difficult to categorize, and will often require a methodical analysis process that considers the economics of each machine and its service.

Trendmaster® – Targeting Tier 2 "Essential" Equipment Assets

Historically, we have found that equipment in Tiers 2-3 has been addressed by a manual data collection program utilizing a portable instrument to take periodic readings and measurements. However, over the past 10-15 years, those machines that fall into the Tier 2 category in our table have been an increasing source of concern to our customers, who are not always able to meet their objectives using a manual data collection strategy. They have expressed needs such as the following:

WHAT CUSTOMERS SAY ...

- *"Failure on these equipment assets seems to be related to process conditions, but by gathering data only once a month or so, it is impossible to establish any kind of meaningful correlation or cause/effect understanding. I may be able to identify the parts that are failing, but can't always* ***stop*** *them from failing by getting to root cause."*
- *"I catch some failures, but others spring up faster than my data collection interval can cover, and I can't afford to collect data more frequently by hand."*
- *"I'd like to collect data, but the places I need to make measurements on these equipment assets are too hazardous or inaccessible."*
- *"The facility is remote and/or un-staffed. It is too expensive to send someone in just to manually collect data."*
- *"These assets don't warrant the same type of system as my critical assets, but I don't feel like I have any alternative if I want continuous monitoring."*
- *"I take portable readings, but I'm not happy with the variation I get with hand-held transducers from one day to the next. I think permanently mounted transducers would provide better results."*
- *"My labor costs are rising and my staff is shrinking. I need to automate portions of my condition monitoring program because I can't afford to use people solely to collect data – I need them to focus on fixing identified problems and improving reliability."*
- *"I want to address more than just rotating machinery with my condition monitoring program – I have to maintain fixed equipment in my plant that includes electrical as well as process equipment. I would like a system that could cost effectively bring all my machinery and fixed equipment asset information together into a common tool."*

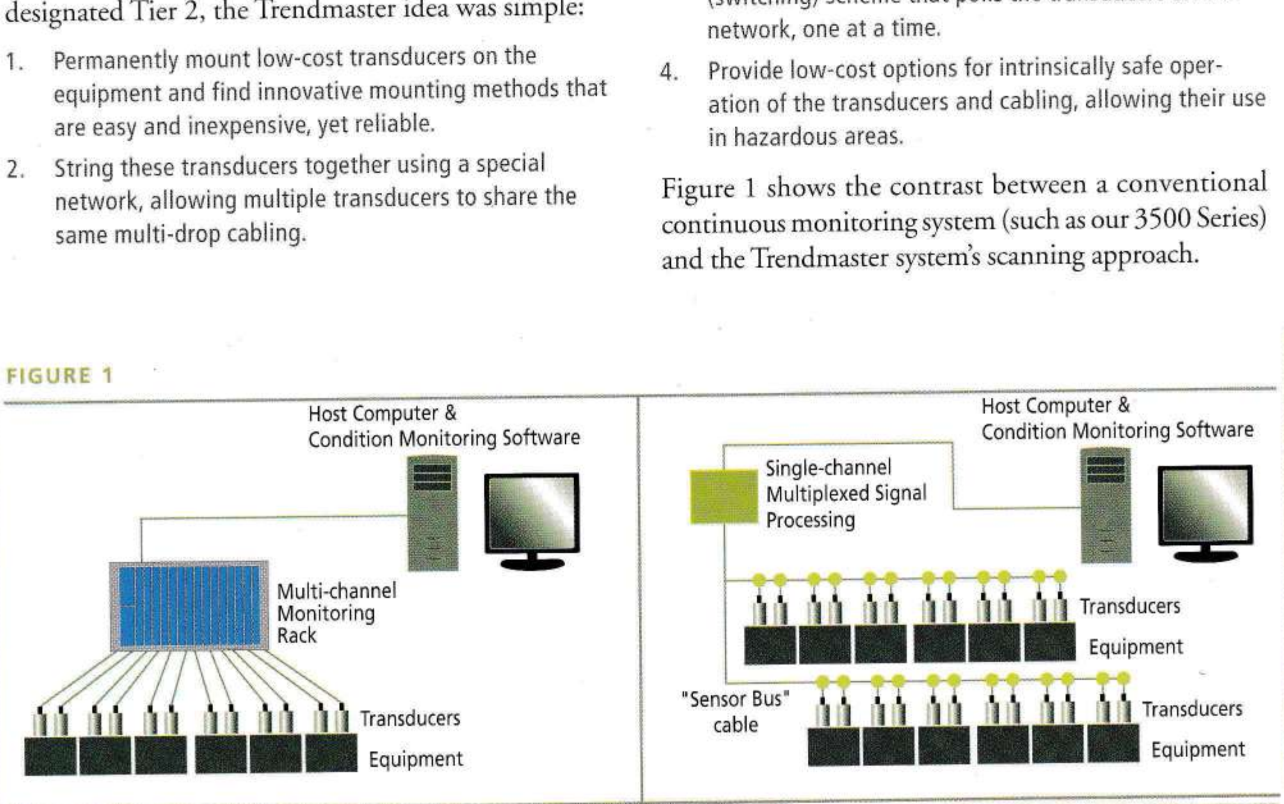
AIMED AT THE CATEGORY OF ASSETS WE'VE DESIGNATED TIER 2,
THE TRENDMASTER IDEA WAS SIMPLE

These types of industry needs first prompted Bently Nevada to develop the Trendmaster® 2000 system back in 1989. Aimed at the category of assets we've designated Tier 2, the Trendmaster idea was simple:

1. Permanently mount low-cost transducers on the equipment and find innovative mounting methods that are easy and inexpensive, yet reliable.
2. String these transducers together using a special network, allowing multiple transducers to share the same multi-drop cabling.
3. Instead of individual monitor channels dedicated to each transducer, "share" a single monitor across all transducers in the system using a multiplexing (switching) scheme that polls the transducers on the network, one at a time.
4. Provide low-cost options for intrinsically safe operation of the transducers and cabling, allowing their use in hazardous areas.

Figure 1 shows the contrast between a conventional continuous monitoring system (such as our 3500 Series) and the Trendmaster system's scanning approach.

FIGURE 1



CONVENTIONAL (NON-SCANNING) CONTINUOUS MONITORING SYSTEM	TRENDMASTER® (SCANNING) QUASI-CONTINUOUS MONITORING SYSTEM
Dedicated channels in a rack-based system are uniquely assigned to each input transducer to perform signal processing and monitor all transducers simultaneously.	A single signal processor is multiplexed among multiple transducers to take measurements in series. Measurements from one transducer are taken, then the system goes to the next transducer and repeats the process.
When installed in hazardous areas, each transducer requires its own intrinsic safety device (e.g., zener diode barrier) – one device per transducer.	When installed in hazardous areas, a single intrinsic safety device can be used for all transducers on a network (since only a single transducer is powered up at a time) – one device per sensor bus.
Wiring costs are higher because each transducer requires individual field wiring all the way back to the monitor rack.	Wiring costs are lower because a single sensor bus can be used for many transducers.
Data for all channels is collected continuously at very high speeds (multiple times per shaft revolution).	Data is collected intermittently, generally once every few minutes for a moderately sized system (scan rates can vary from seconds to minutes, depending on system size, topology, and configuration settings).
Transducers are not shared among a single monitor; therefore, they do not require a unique address.	Transducers are shared among a single monitor; therefore, they require a device that gives them each a unique address when the monitor is polling the transducers on a bus.

Trendmaster – Finding the Balance

Clearly, Trendmaster represents a less expensive solution for permanent monitoring by using its innovative sensor bus and quasi-continuous scanning architecture. Some might be tempted to conclude that Trendmaster is just as appropriate for high-speed, critical, multi-case machine trains (Tier 1) as it is for "essential" machinery (Tier 2). However, the failure mechanisms of Tier 1 machines can occur very rapidly and require a system that is protecting the machine with every single shaft revolution. Furthermore, diagnostics on these machines are often more complex than those of smaller "essential" machines with only a few bearings and simpler rotor dynamics. For this reason, Bently Nevada continues to advocate, and customers continue to prefer, our continuous machinery protection systems (such as the 3500 series) for Tier 1 assets. When coupled with 3500's built-in TDI communications processor for high-speed, parallel data capture from all transducers simultaneously, such an architecture provides the data acquisition speed needed for diagnostics on these machines, and provides a level of alarming and shutdown protection commensurate with the critical nature of these machines.

In summary, we advocate that the Trendmaster system can be applied on any class of asset (Tier 2-4) except "critical" (Tier 1). However, the economics of the situation will generally dictate that "essential" (Tier 2) is the most appropriate category for Trendmaster applications. In the petrochemical industries, Tier 2 frequently includes pumps and motors, particularly those that can have bearing or seal failures that progress relatively rapidly and can result in not just broken machines, but possibly fires or the release of hazardous substances. Additionally, other machines often included in Tier 2 include cooling tower fans, heat exchanger fin fans, blowers, small single-stage steam turbines, fixed equipment, and others. We have also seen widespread deployment of Trendmaster systems in the cement industry, in pharmaceutical plants, in the mining industry, in power generation facilities for "balance of plant" assets – and anywhere else that online mechanical health monitoring of important assets is warranted.

Trendmaster – The Architecture

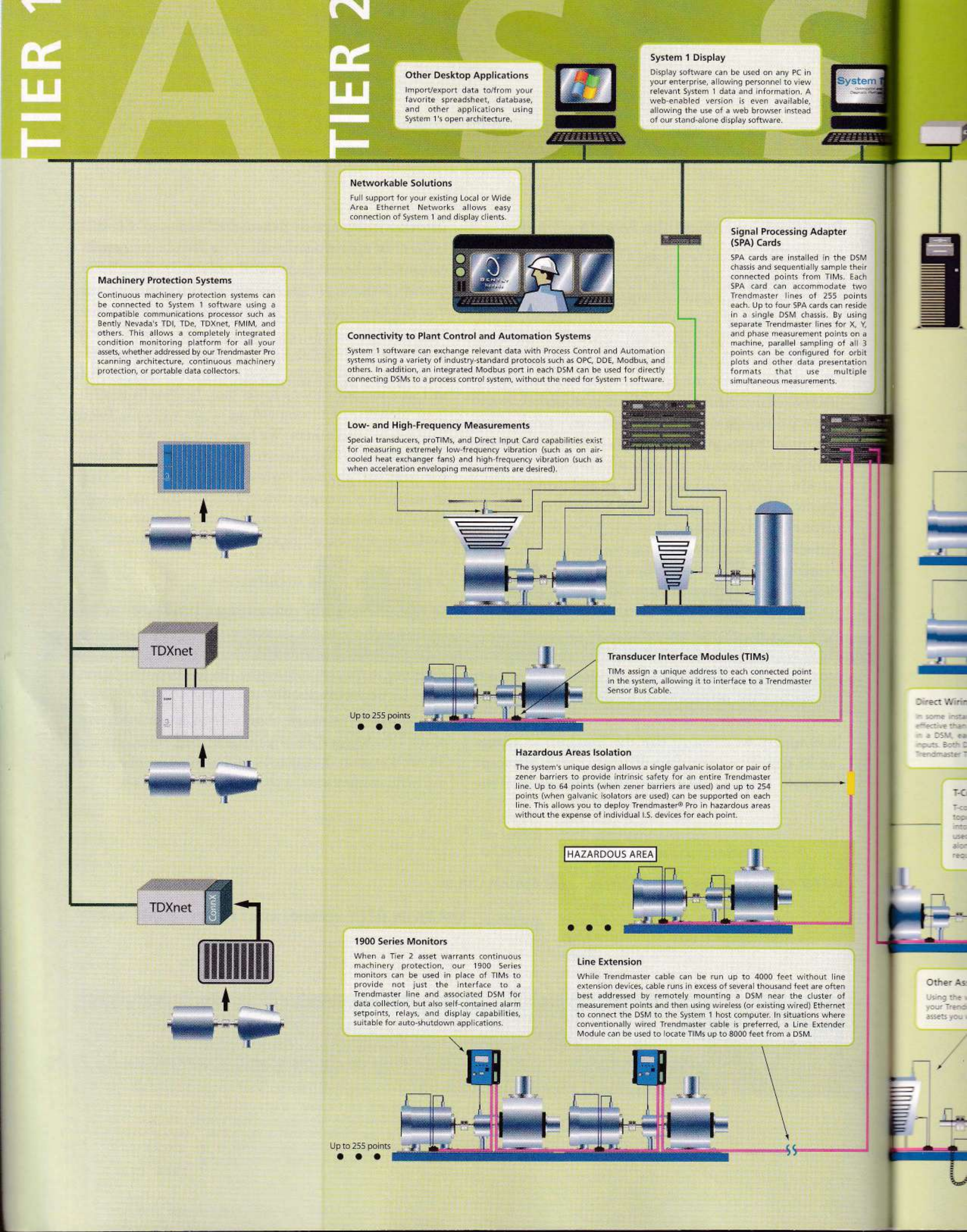
In Figure 1, we briefly contrasted the Trendmaster architecture with that of a conventional continuous monitoring system. We intentionally over-simplified the diagrams to quickly summarize the fundamental differences between our scanning and non-scanning offerings.

The following two pages show a more detailed diagram of the Trendmaster® Pro architecture. Beginning on page 38, we'll explain the function and capabilities of each of the main components in the architecture diagram.

WE ADVOCATE THAT THE TRENDMASTER SYSTEM CAN BE APPLIED ON ANY CLASS OF ASSET EXCEPT "CRITICAL"

MONITORING IS IN THE WIND

Did you know that our new Wind Turbine Monitoring System is based on the Trendmaster Pro platform? To learn more about these machines and how our Trendmaster Pro system can reduce maintenance costs and unplanned outages, see our feature-length article beginning on page 20 in this issue of ORBIT.



Other Desktop Applications

Import/export data to/from your favorite spreadsheet, database, and other applications using System 1's open architecture.

System 1 Display

Display software can be used on any PC in your enterprise, allowing personnel to view relevant System 1 data and information. A web-enabled version is even available, allowing the use of a web browser instead of our stand-alone display software.

Networkable Solutions

Full support for your existing Local or Wide Area Ethernet Networks allows easy connection of System 1 and display clients.

Machinery Protection Systems

Continuous machinery protection systems can be connected to System 1 software using a compatible communications processor such as Bently Nevada's TDI, TDe, TDXnet, FMIM, and others. This allows a completely integrated condition monitoring platform for all your assets, whether addressed by our Trendmaster Pro scanning architecture, continuous machinery protection, or portable data collectors.

Connectivity to Plant Control and Automation Systems

System 1 software can exchange relevant data with Process Control and Automation systems using a variety of industry-standard protocols such as OPC, DDE, Modbus, and others. In addition, an integrated Modbus port in each DSM can be used for directly connecting DSMs to a process control system, without the need for System 1 software.

Signal Processing Adapter (SPA) Cards

SPA cards are installed in the DSM chassis and sequentially sample their connected points from TIMs. Each SPA card can accommodate two Trendmaster lines of 255 points each. Up to four SPA cards can reside in a single DSM chassis. By using separate Trendmaster lines for X, Y, and phase measurement points on a machine, parallel sampling of all 3 points can be configured for orbit plots and other data presentation formats that use multiple simultaneous measurements.

Low- and High-Frequency Measurements

Special transducers, proTIMs, and Direct Input Card capabilities exist for measuring extremely low-frequency vibration (such as on air-cooled heat exchanger fans) and high-frequency vibration (such as when acceleration enveloping measurments are desired).

Transducer Interface Modules (TIMs)

TIMs assign a unique address to each connected point in the system, allowing it to interface to a Trendmaster Sensor Bus Cable.

Hazardous Areas Isolation

The system's unique design allows a single galvanic isolator or pair of zener barriers to provide intrinsic safety for an entire Trendmaster line. Up to 64 points (when zener barriers are used) and up to 254 points (when galvanic isolators are used) can be supported on each line. This allows you to deploy Trendmaster® Pro in hazardous areas without the expense of individual I.S. devices for each point.

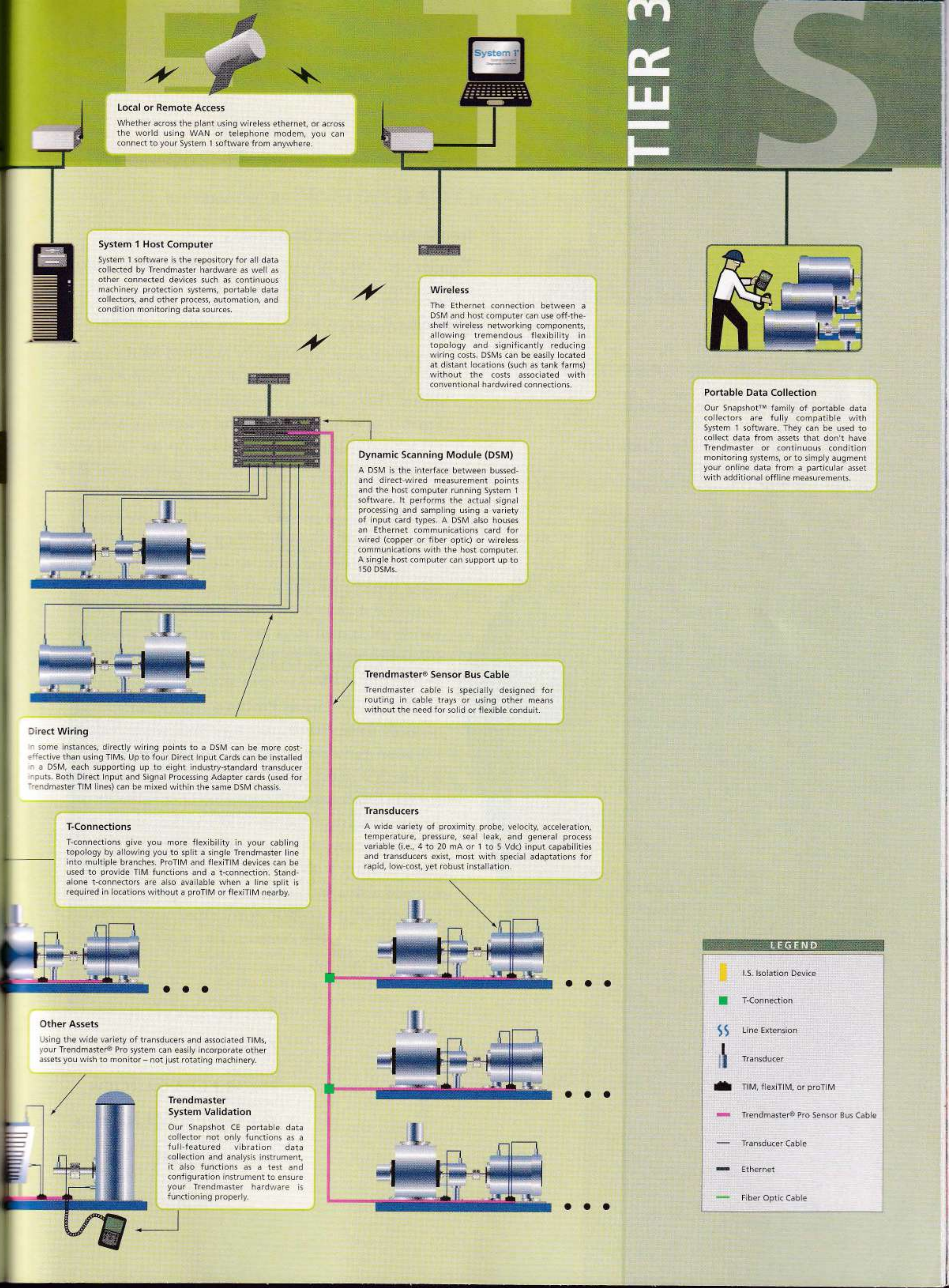
1900 Series Monitors

When a Tier 2 asset warrants continuous machinery protection, our 1900 Series monitors can be used in place of TIMs to provide not just the interface to a Trendmaster line and associated DSM for data collection, but also self-contained alarm setpoints, relays, and display capabilities, suitable for auto-shutdown applications.

Line Extension

While Trendmaster cable can be run up to 4000 feet without line extension devices, cable runs in excess of several thousand feet are often best addressed by remotely mounting a DSM near the cluster of measurement points and then using wireless (or existing wired) Ethernet to connect the DSM to the System 1 host computer. In situations where conventionally wired Trendmaster cable is preferred, a Line Extender Module can be used to locate TIMs up to 8000 feet from a DSM.

TIER 3



Local or Remote Access

Whether across the plant using wireless ethernet, or across the world using WAN or telephone modem, you can connect to your System 1 software from anywhere.

System 1 Host Computer

System 1 software is the repository for all data collected by Trendmaster hardware as well as other connected devices such as continuous machinery protection systems, portable data collectors, and other process, automation, and condition monitoring data sources.

Wireless

The Ethernet connection between a DSM and host computer can use off-the-shelf wireless networking components, allowing tremendous flexibility in topology and significantly reducing wiring costs. DSMs can be easily located at distant locations (such as tank farms) without the costs associated with conventional hardwired connections.

Dynamic Scanning Module (DSM)

A DSM is the interface between bussed- and direct-wired measurement points and the host computer running System 1 software. It performs the actual signal processing and sampling using a variety of input card types. A DSM also houses an Ethernet communications card for wired (copper or fiber optic) or wireless communications with the host computer. A single host computer can support up to 150 DSMs.

Direct Wiring

In some instances, directly wiring points to a DSM can be more cost-effective than using TIMs. Up to four Direct Input Cards can be installed in a DSM, each supporting up to eight industry-standard transducer inputs. Both Direct Input and Signal Processing Adapter cards (used for Trendmaster TIM lines) can be mixed within the same DSM chassis.

Trendmaster® Sensor Bus Cable

Trendmaster cable is specially designed for routing in cable trays or using other means without the need for solid or flexible conduit.

T-Connections

T-connections give you more flexibility in your cabling topology by allowing you to split a single Trendmaster line into multiple branches. ProTIM and flexiTIM devices can be used to provide TIM functions and a t-connection. Stand-alone t-connectors are also available when a line split is required in locations without a proTIM or flexiTIM nearby.

Transducers

A wide variety of proximity probe, velocity, acceleration, temperature, pressure, seal leak, and general process variable (i.e., 4 to 20 mA or 1 to 5 Vdc) input capabilities and transducers exist, most with special adaptations for rapid, low-cost, yet robust installation.

Other Assets

Using the wide variety of transducers and associated TIMs, your Trendmaster® Pro system can easily incorporate other assets you wish to monitor – not just rotating machinery.

Trendmaster
System Validation

Our Snapshot CE portable data collector not only functions as a full-featured vibration data collection and analysis instrument, it also functions as a test and configuration instrument to ensure your Trendmaster hardware is functioning properly.

Portable Data Collection

Our Snapshot™ family of portable data collectors are fully compatible with System 1 software. They can be used to collect data from assets that don't have Trendmaster or continuous condition monitoring systems, or to simply augment your online data from a particular asset with additional offline measurements.

LEGEND

▮	I.S. Isolation Device
🟩	T-Connection
ʃʃ	Line Extension
▮	Transducer
▬	TIM, flexiTIM, or proTIM
▬	Trendmaster® Pro Sensor Bus Cable
—	Transducer Cable
▬	Ethernet
—	Fiber Optic Cable

A TRENDMASTER PRO SYSTEM CONSISTS OF...

❶ *Transducers*

❷ *Transducer Interface Modules*

❸ *Cabling and Accessories*

❹ *Dynamic Scanning Module(s)*

❺ *Host Software (System 1®)*

COMPATIBLE TRENDMASTER PRO INPUT TYPES...

- Vibration and position transducers including proximity probes, moving-coil and solid-state velocity transducers, and accelerometers
- Thermocouples and RTDs
- A special-purpose seal-leak detection transducer
- Oil condition sensors
- Pressure transducers
- Generic proportional current signals (e.g., 4-20 mA)
- Generic dynamic voltage signals from third-party transducers or monitor system buffered outputs
- Speed and phase reference (Keyphasor®) transducers

Trendmaster – The Components

Trendmaster Pro consists of five main components, and we consider each of these in order.

❶ *Transducers*

Transducers are permanently mounted on the assets and make the fundamental condition measurements. The signals can be brought into the Trendmaster Pro system either via a Transducer Interface Module (TIM), or via direct wiring to an appropriate Dynamic Scanning Module (DSM) card. Also, if a signal for which dynamic data is not required is already being brought into a process control system and could provide valuable condition monitoring information, hard-wiring can be used as above, or circumvented altogether via an appropriate digital interface between the process control system and System 1 software. A very wide variety of transducers and input signal types are compatible with the Trendmaster Pro system, as shown in the table at left.

Generally, Trendmaster Pro can accept vibration measurements made with virtually any commercially available vibration transducer; however, the most cost-effective approach is to use transducers developed specifically for the Trendmaster Pro system. These address the simultaneous requirements of low cost, rapid and inexpensive mounting, hazardous area certification, compatibility with our newest TIMs, robust environmental design that doesn't require special housings, and performance characteristics that meet or exceed the diagnostic requirements of most Tier 2 and Tier 3 assets.

TRENDMASTER CUSTOMERS CAN USE PORTABLE DATA COLLECTION TO COMPLEMENT THEIR ONLINE PROGRAM

THE MOST COST-EFFECTIVE APPROACH IS TO USE TRANSDUCERS DEVELOPED SPECIFICALLY FOR THE TRENDMASTER PRO SYSTEM

Frequently, rotating machines in Tier 2 and Tier 3 use rolling element bearings, and the appropriate vibration transducers will often be seismic (velocity or acceleration) rather than shaft-observing proximity probes. This article does not attempt to provide detailed information on every transducer compatible with the Trendmaster Pro system and confines itself to a summary of only our most recent seismic transducer offerings. For a more complete overview of all compatible transducers and associated TIMs, visit our website where a wealth of such information is available.

TRENDMASTER FAMILY OF ACCELEROMETERS

PRODUCT	DESCRIPTION	COMPATIBLE TIM TYPES	
200150 **ACCELEROMETER**	This general-purpose accelerometer was previously housed in a plastic case but has been recently redesigned with a more robust stainless steel case. It is designed to address casing vibration measurements on the majority of Tier 2 and Tier 3 machines appropriate for inclusion in a Trendmaster Pro system. It is compatible with our new 200200 and 200250 proTIMs, as well as previous generation accel-to-velocity TIMs and flexiTIMs.	• 200250 proTIM-C • 200200 proTIM-R • 200100 Accel-to-Velocity flexiTIM • 89130 Accel-to-Velocity TIM • 89546 Accel-to-Velocity TIM (intrinsically safe version)	
200155 **LOW-FREQUENCY ACCELEROMETER**	The 200155 is visually identical to the 200150, but offers an extended low-frequency response intended for applications involving low-speed (below 600 rpm) machinery such as cooling towers and fin fans.	• 200250 proTIM-C • 200200 proTIM-R	
200157 **HIGH-FREQUENCY ACCELEROMETER**	This transducer is also visually identical to the 200150, but designed for applications where acceleration enveloping measurements are required in addition to the basic measurements provided by a 200150.	• 200250 proTIM-C • 200200 proTIM-R	
200350 & **200355** **ACCELEROMETERS**	These transducers are used when economic and/or performance considerations make it desirable to wire a seismic measurement point directly to a DSM, rather than using Trendmaster's multi-drop cable and a proTIM. This topic is discussed in more detail later in this article in the section on DSMs. The 200350 is used for conventional and acceleration enveloping applications. The 200355 is used primarily for low-frequency applications.	• Compatible only with DSM Seismic Direct Input Card	

learn more online at:
`http://www.bently.com/prod/products/trendmasterprotims.htm`

OUR NEW PROTIMS ARE EASIER TO INSTALL AND TO CONFIGURE, PROVIDE BETTER SELF-DIAGNOSTIC CAPABILITIES, AND CAN MIX AND MATCH CHANNEL TYPES

❷ *Transducer Interface Modules (TIMs)*

TIMs are analogous to the numbers on the front of a house, allowing people to distinguish it from others along the same street. In the same way, TIMs are used to assign a unique address to each transducer or signal input location along Trendmaster's sensor bus. TIMs also provide selected signal processing functions for the basic transducer measurement. Over the years, TIMs have taken on several different physical form factors, as shown in the summary table. With the introduction of the Trendmaster Pro system, we're also pleased to introduce an entirely redesigned TIM package – proTIMs. Our new proTIMs are easier to install, easier to configure, provide better self-diagnostic capabilities, and can mix and match channel types. The result is better performance, lower installation costs, and lower costs of ownership.

EVOLUTION OF TRANSDUCER INTERFACE MODULES (TIMs)

TYPE	DESCRIPTION	COMPATIBILITY	
TIMs *1st Generation*	Available in both standard and intrinsically safe versions, these TIMs required a special tool to connect Trendmaster cabling to their connectors. They could be DIN-rail mounted, or mounted flat against a wall or junction box. However, they are not ATEX approved and are diminishing in use in favor of newer TIM designs such as flexiTIMs and proTIMs.	• Trendmaster Pro • Trendmaster 2000	
flexiTIMs *2nd Generation*	This package introduced a 2-channel design, which was found to optimize installation costs in most applications. It also allowed the TIM to be easily mounted on a conduit body, facilitating installation without the requirement for junction boxes – further reducing installation costs.	• Trendmaster Pro • Trendmaster 2000	
proTIMs *3rd Generation*	Our newest TIM package retains the 2-channel design of flexiTIMs, but offers two different form factors for bulkhead or conduit mounting (200200 proTIM-C) or DIN-rail mounting (200250 proTIM-R). ProTIMs also feature various software-programmable configuration capabilities, eliminating manual DIP switches for address coding. Channel types can be mixed and matched for optimal installation flexibility and lower costs by ensuring you minimize "stranded" (unused) channels. You may choose between any of the following channel types: • Accel-to-Velocity (standard, low-frequency, or acceleration enveloping) • K-type Thermocouple • 2-, 3-, or 4-wire Platinum RTD	• Trendmaster Pro • Trendmaster 2000	

learn more online at:

`http://www.bently.com/prod/products/trendmasterprotims.htm`

CABLING FORMS THE BACKBONE OF THE SYSTEM,
LINKING THOUSANDS OF MEASUREMENT POINTS TO A DYNAMIC SCANNING MODULE

③ *Cabling and Accessories*

Trendmaster Pro retains the same cabling as previous generations. Cabling forms the backbone of the system, linking thousands of measurement points to a Dynamic Scanning Module.

The cable has been designed for use with or without conduit, and, when used with appropriate zener barriers or galvanic isolators (both are available from Bently Nevada), is approved for use in Division 1 and Zone 0 hazardous areas. An innovative feature of Trendmaster is its ability to support multiple measurement points with a single galvanic isolator or pair of zener diode barriers – a feature that dramatically reduces installation costs and simplifies ongoing instrument and grounding system maintenance.

A variety of accessories are available, such as T-connectors, allowing virtually any desired network topology.

Also new to Trendmaster Pro is a more convenient approach for system testing and configuration. Previously, a stand-alone, single-purpose TIM Tester instrument was required. Today, we've replaced the need for a separate instrument, and instead embedded the test and configuration functionality into our Snapshot™ for Windows® CE portable data collector. Why? We have found that Trendmaster customers use portable data collection to complement their online program. For example, when a machine exhibits the early signs of failure, a technician may be deployed to collect additional data with Snapshot CE, augmenting the data collected by the Trendmaster system. Or, the Trendmaster Pro system, using its embedded Decision Support℠ capabilities, might automatically determine that the machine needs to be balanced. Snapshot CE can be used to perform the field balancing calculations. Since most users will already have a Snapshot CE data collector for these purposes, it made sense to embed our TIM Tester functions in this same instrument. You can read more about the new TIM Tester capabilities in Snapshot CE on page 17 in our First Quarter 2004 issue of ORBIT.

GALVANIC ISOLATION

Zener barriers require a high-integrity earth ground connection that represents ongoing maintenance requirements, particularly in environments such as offshore platforms and others that give rise to corrosion and compromise the integrity of ground connections. Our new Galvanic Isolator is preferred by many customers when installing a Trendmaster Pro system in hazardous areas because it *eliminates* the need for a ground connection altogether by using transformer coupling rather than current-limiting diodes. The result is a safer installation that is less prone to degradation over time and requires no recurring maintenance.

The original TIM Tester was a single-purpose device...

Now, TIM Tester functionality is built-in to our Snapshot CE portable data collector.

❹ *Dynamic Scanning Module*

One of the most significant enhancements to Trendmaster in recent years is the introduction, in Trendmaster Pro, of our new Dynamic Scanning Module (DSM). A DSM is the bridge between a Trendmaster "sensor bus" and the host computer running System 1® software. Previously, a Trendmaster sensor bus terminated in a special set of data sampling cards (Signal Processing Adapters or SPAs) that resided inside a compatible PC. Today, the use of an external module (the DSM) to house an all-new SPA card allows considerably more installation flexibility than a card set inside the host computer.

The DSM also enhances performance and reduces installation costs – dramatically in some circumstances – by limiting the amount and type of wire that must be run because it uses standard Ethernet between itself and the host computer. This network cabling already exists in most plants and completely eliminates the need to install "home run" cabling between clusters of Trendmaster points and the host computer. And, where cabling does not exist, off-the-shelf wireless Ethernet can also be used. For those customers that want conventional "hard-wired" network communications, conventional copper wire as well as fiber-optic cable can be used. Fiber-optic cable allows signal wiring to be installed in the same conduit as power wiring without being affected by noise and interference. This opens new possibilities for retrofit situations that help keep installation costs minimized.

Finally, we have specifically designed Trendmaster such that the required bandwidth on an existing Ethernet network within the plant is minimized. In almost all cases, Trendmaster can co-exist on existing plant networks rather than requiring its own dedicated network.

A single DSM can accommodate up to four signal input modules, in addition to a copper or fiber-optic Ethernet communications card. Currently, there are four different types of signal input cards as follows:

DSM CARD TYPES

TYPE	DESCRIPTION	COMPATIBLE TRANSDUCERS
TIM Input Card	Replaces the role of previous-generation Signal Processing Adapters. Directly compatible with existing TIM cables and connectors. Each card can accept up to two Trendmaster sensor bus cables, with each sensor bus supporting a maximum of 255 points* (510 per card).	• All previous-generation transducers and TIMs supported by Trendmaster 2000, Trendmaster 2000 for Windows®, as well as new proTIMs and their compatible transducers.
Process Variable Direct Input Card	Allows up to 8 points of 4-20 mA signals to be directly wired into the Trendmaster Pro system, without the use of TIMs	• Most industry standard "loop powered" 4-20 mA devices; the DSM supplies the required power.
24 Volt Transducer Direct Input Card	Allows up to 8 points of –24V 3-wire voltage-mode transducers (generally, proximity probes or non current-mode accelerometers) to be directly wired into the Trendmaster Pro system, without the use of TIMs	• 3300, 3300 XL, 3300 REBAM®, and 7200 Series proximity transducers • 23732, 330400, and 330425 accelerometers
Seismic Direct Input Card	Allows up to 8 points of 2-wire constant-current accelerometer or velocity signals to be directly wired into the Trendmaster Pro system, without the use of TIMs. Provides enhanced signal conditioning capabilities, including acceleration enveloping.	• 200350 and 200355 accelerometers • 330500, 330525, and 190501 Velomitor® piezo-velocity transducers

* *When intrinsically safe barriers are used, the number of TIMs supported will be less for each line. The total number of points supported is a function of cable length. Contact your Bently Nevada sales professional for additional information.*

learn more online at:
`http://www.bently.com/prod/products/trendmasterprodics.htm`

Also new to Trendmaster Pro is the ability to introduce signals into the system without the use of TIMs or sensor bus cabling. This can be done in two ways. One is through the use of the wide variety of importers in System 1 software, supporting protocols such as Modbus, OPC, and others. This method eliminates wiring altogether, allowing you to use data already resident in a process control or other automation system, and share it with Trendmaster Pro for condition monitoring purposes. Another method is through the use of Direct Input Cards, where compatible sensors are hardwired directly to a DSM.

Why have we introduced direct hardwiring in addition to TIMs – especially after discussing the reduction in installation costs that TIMs and a sensor-bus approach can yield?

We have found that, depending on the number of points and the amount of cable that needs to be run, it can sometimes be less expensive to deploy several DSMs, locate them in strategic areas where there are a cluster of measurement points, and directly wire points to the DSM without the use of TIMs and lengthy runs of sensor bus cables. Determining the least-cost option will be unique to each installation and is beyond the scope of this article. However, your Bently Nevada sales professional has a variety of tools available to assist you in comparing costs and determining the optimal architecture for your particular situation.

IN ALMOST ALL CASES, **TRENDMASTER CAN CO-EXIST** ON EXISTING PLANT **NETWORKS** RATHER THAN REQUIRING ITS OWN **DEDICATED** NETWORK

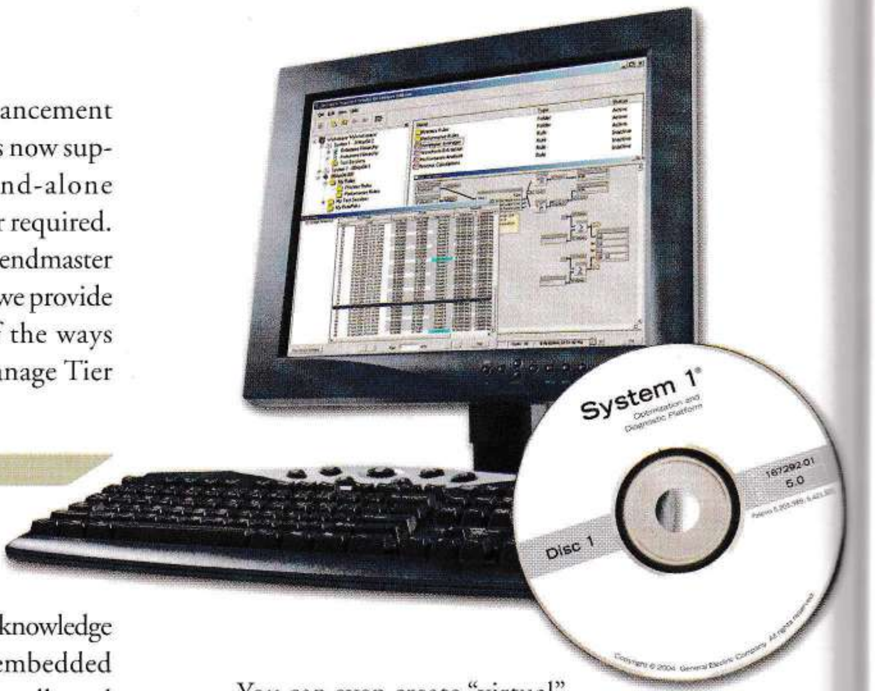
New Modbus® Interface Flexibility for DSMs

For customers requiring only a basic trending system without advanced condition monitoring and Decision Support℠ features, Trendmaster Pro hardware can now be used *without* System 1® software. How? By using the integrated Modbus port in a DSM, allowing direct connection to a process control or automation system using this industry-standard protocol. This allows the process control system to acquire data directly from DSMs, perform all trending and alarming, and thus integrate basic equipment health statuses and trends with the other information in the process control system. While considerably less capable than Trendmaster implementations that use System 1 software, this new "direct connect" option represents a cost-effective, entry-level approach for facilities that want to start with a basic system and then progress to more sophisticated capabilities in the future. Also, both Modbus and System 1 connections can be used simultaneously, for those who need to send data to their condition monitoring platform and their process control system.

DECISION SUPPORT HELPS BRING THE BENEFITS OF CONDITION MONITORING DOWN TO THE MOST DIRECT AND IMMEDIATE LEVELS OF INTERVENTION IN YOUR PLANT – YOUR OPERATIONS PERSONNEL

5 *Host Software*

Perhaps the single most dramatic enhancement to our Trendmaster platform is that it is now supported by System 1 software – stand-alone Trendmaster 2000 software is no longer required. System 1 delivers all the capabilities of Trendmaster 2000 software, plus many others. Here, we provide a partial summary detailing some of the ways System 1 improves your ability to manage Tier 2 equipment assets.



Decision Support℠

No discussion of System 1 software is complete without describing its Decision Support℠ capabilities. Decision Support allows you to embed knowledge and rules in System 1, and use that embedded intelligence to automatically analyze collected data – spectral content, waveform shape, trends, rate-of-change, alarm statuses, and any other data attribute. This provides 24/7 automated data interrogation, event detection, and user notification, allowing you to benefit from not only the basic alarming provided in System 1 software, but also advanced "intelligent" alarming and event detection based on sophisticated, user-configurable multi-parameter conditions.

WIRELESS EQUALS LESS COST

Trendmaster Pro has been specifically designed to take advantage of today's tremendous selection of off-the-shelf wireless Ethernet products. This allows Dynamic Scanning Modules (DSMs) to be placed in virtually any location, without the constraint of a hardwired network connection for communication with System 1 software. Simply use the DSM's Ethernet port to interface with appropriate wireless hardware, and you're part of the network. Wired and wireless connections can seamlessly co-exist, allowing maximum flexibility in where and how you locate DSMs as part of your system. The result is faster, easier deployment of a Trendmaster Pro system, with lower installation costs than ever before.

You can even create "virtual" variables using a variety of mathematical and logical operators by combining measured data into entirely new derived measurements. These derived measurements can then be used like any directly measured variable.

The user-friendly rule writing environment of System 1 was specifically designed to relieve users of burdensome and complex programming languages. Writing new rules and embedding your equipment and process knowledge is as simple as building a graphical flow chart showing the criteria you want to use to detect a particular condition. Blocks of rules can be combined into larger blocks, allowing the creation of extremely sophisticated inference engines that are completely custom to your process, your plant, your operating procedures, and your equipment's behavior and failure mechanisms.

While such capabilities have long been available with our online software for "critical" equipment, this marks the first time we have made them available to the less-critical equipment that is

SYSTEM 1 COMBINES ALL EQUIPMENT ASSET CLASSIFICATIONS INTO A SINGLE CONDITION MONITORING PLATFORM

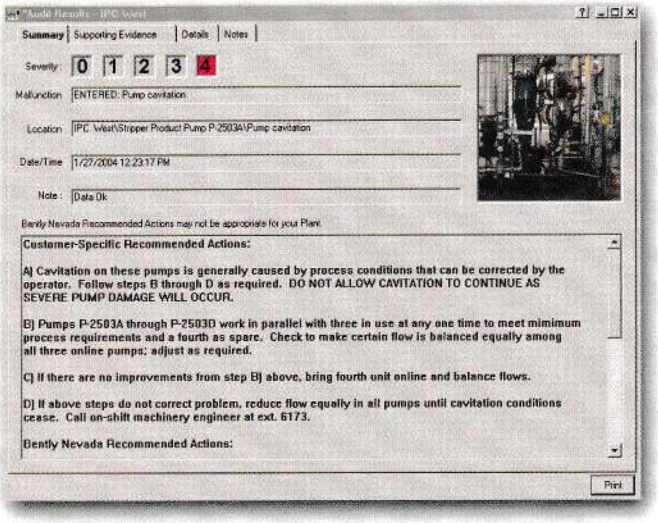
part of your condition monitoring program. Decision Support helps bring the benefits of condition monitoring down to the most direct and immediate levels of intervention in your plant – your operations personnel. For example, consider a plant that uses centrifuges to separate liquids and solids as part of their process. Centrifuges often fall into the "Tier 2" classification and are therefore good candidates for our Trendmaster Pro system. A typical centrifuge scenario is that they become unbalanced as solids build-up non-uniformly on the rotating components. Left undetected, this unbalance can cause premature failure of bearings, seals, and other components. Using Decision Support, unbalance can be easily detected and distinguished from other malfunctions. Operators can be notified immediately, and maintenance can be scheduled – often to simply wash the machine and remove the build-up. However, Decision Support can also be used to detect other problems such as bearing wear, foundation bolt looseness, misalignment, and motor winding problems. Timely, intelligent advisories can be provided to operators and maintenance personnel allowing them to take the right actions at the right time.

In addition to user-written rules, Bently Nevada also provides embedded knowledge in pre-configured "packages" for a wide variety of machines and malfunctions. These RulePaks can easily be augmented with your own rules.

While users can customize rules and inferences used to detect condition degradation, the notification methods and messages can also be customized. When a condition has been detected (using our rules, your rules, or a combination of the two), you can decide exactly who to notify, when to notify them, how to notify them (cell phone, pager, e-mail, process control system annunciator, etc.), and what to tell them – using plain language rather than data and plots requiring specialized interpretation.

Common Environment

System 1 combines all equipment asset classifications into a single condition monitoring platform. Portable data collection, online scanning systems (i.e., Trendmaster Pro), protection systems, and manually collected notes and data can all be combined. This equates to fewer systems to learn, use, and maintain, lowering your costs and helping make the system more accessible to a wider variety of personnel in your plant who can contribute to the asset management function.



Severity: 0 1 2 3 4

Malfunction: ENTERED: Pump cavitation

Location: IPC West\Stripper Product Pump P-2503A\Pump cavitation

Date/Time: 1/27/2004 12:23:17 PM

Note: Data Ok

Bently Nevada Recommended Actions may not be appropriate for your Plant

Customer-Specific Recommended Actions:

A] Cavitation on these pumps is generally caused by process conditions that can be corrected by the operator. Follow steps B through D as required. DO NOT ALLOW CAVITATION TO CONTINUE AS SEVERE PUMP DAMAGE WILL OCCUR.

B] Pumps P-2503A through P-2503D work in parallel with three in use at any one time to meet mimimum process requirements and a fourth as spare. Check to make certain flow is balanced equally among all three online pumps; adjust as required.

C] If there are no improvements from step B] above, bring fourth unit online and balance flows.

D] If above steps do not correct problem, reduce flow equally in all pumps until cavitation conditions cease. Call on-shift machinery engineer at ext. 6173.

Bently Nevada Recommended Actions:

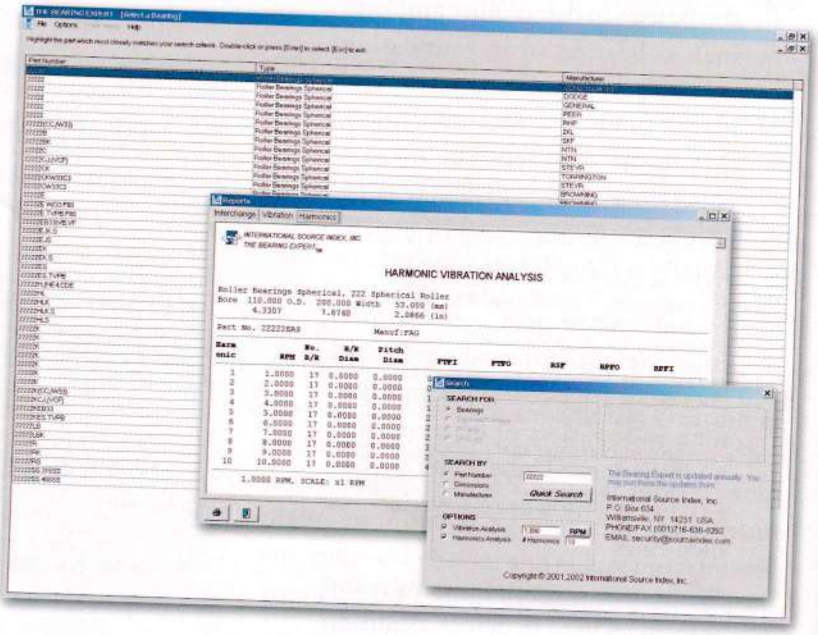
Now, automated data analysis and intelligent advisories can be extended to the equipment assets monitored by Trendmaster Pro – using System 1 software's powerful Decision Support^{SM} capabilities

Because a single system and single database are used, multiple data collection methods and condition monitoring technologies can be combined. For example, it might be desirable to augment measurements made by Trendmaster Pro on a pump/motor set with some portable data collector readings taken on surrounding piping or other places where permanent measurements are not available. Data from our portable data collector can be easily integrated into the same database, plots, and reports used by the Trendmaster Pro system. If a separate tool is used to provide periodic alignment, this data can likewise be accessed using the DocuView™ features of System 1, allowing you to provide links from within System 1 to many other asset-related information sources. For example, right-clicking on the graphic showing the motor/pump set in the example above could provide a list of related links such as websites with manufacturer data, documents in your own data control library with assembly drawings and maintenance manuals, logs and maintenance history data in your CMMS, pump curves, motor data sheets, and just about any other file, website, or application accessible from your corporate network.

Bearing Library

System 1 interfaces directly to The Bearing Expert™ software from International Source Index, Inc. This software is a constantly growing catalog of over one million rolling element bearings. Its integration with System 1 makes it easier for users to access bearing information, establish trends and spectral band alarms for specific frequency components, and perform diagnostics on those

DATA FROM OUR **PORTABLE DATA COLLECTOR** CAN BE EASILY **INTEGRATED** INTO THE **SAME** DATABASE, PLOTS, AND REPORTS USED BY THE **TRENDMASTER PRO SYSTEM**

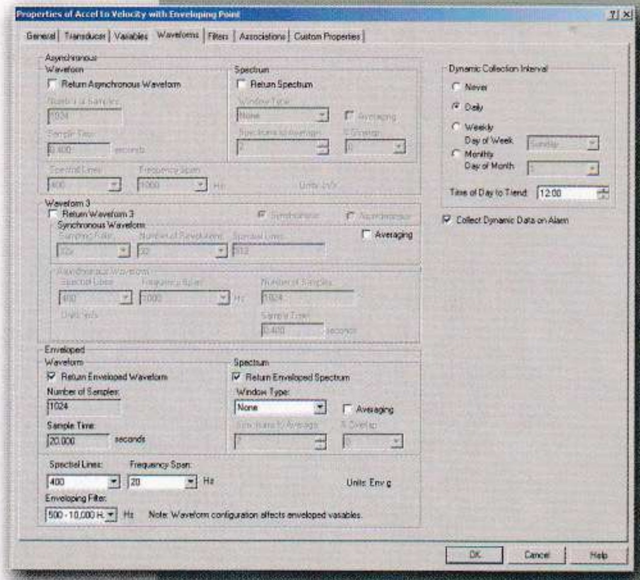


Users can easily import frequencies for over one million rolling element bearings via The Bearing Expert™ software from ISI – a System 1-compatible application.

machines that use rolling element bearings. Also included in the database are widespread vibration and interchange data such as AFBMA (Anti-Friction Bearing Manufacturers Association) numbers, bearing diagrams/dimensions, manufacturers, part numbers, prefix and suffix descriptions, extended harmonics reporting, and cross-reference information.

Acceleration Enveloping

System 1 is able to store, display, and process the acceleration enveloping data provided by compatible hardware – such as selected Trendmaster proTIMs, Trendmaster Pro Direct Input Cards, and Snapshot CE and IS data collection instruments. Acceleration enveloping is a powerful signal processing tool that can provide earlier warning of bearing failure and other malfunctions, and is particularly useful in rolling-element bearing machinery common to Tiers 2, 3, and 4. You can read more about acceleration enveloping in our feature-length article on page 10.



Asynchronous
Waveform
☐ Return Asynchronous Waveform
Number of Samples: 1024
Sample Time: 0.400 seconds
Spectrum
☐ Return Spectrum
Window Type: None
☐ Averaging
Spectral Lines: 400
Frequency Span: 1000 Hz
Units: in/s

Waveform 3
☐ Return Waveform 3
● Synchronous ○ Asynchronous
Synchronous Waveform
☐ Averaging
Spectral Lines: 512
Asynchronous Waveform
Spectral Lines: 400
Frequency Span: 1000 Hz
Units: in/s
Number of Samples: 1024
Sample Time: 0.400 seconds

Enveloped
Waveform
☑ Return Enveloped Waveform
Number of Samples: 1024
Sample Time: 20.000 seconds
Spectrum
☑ Return Enveloped Spectrum
Window Type: None
☐ Averaging
Spectral Lines: 400
Frequency Span: 20 Hz
Units: Env g
Enveloping Filter: 500 - 10,000 Hz
Note: Waveform configuration affects enveloped vasables.

Dynamic Collection Interval
○ Never
● Daily
○ Weekly
Day of Week: Sunday
○ Monthly
Day of Month: 1
Time of Day to Trend: 12:00
☑ Collect Dynamic Data on Alarm

Seismic transducers can now be configured to return acceleration enveloping data in addition to other measurements.

Summary

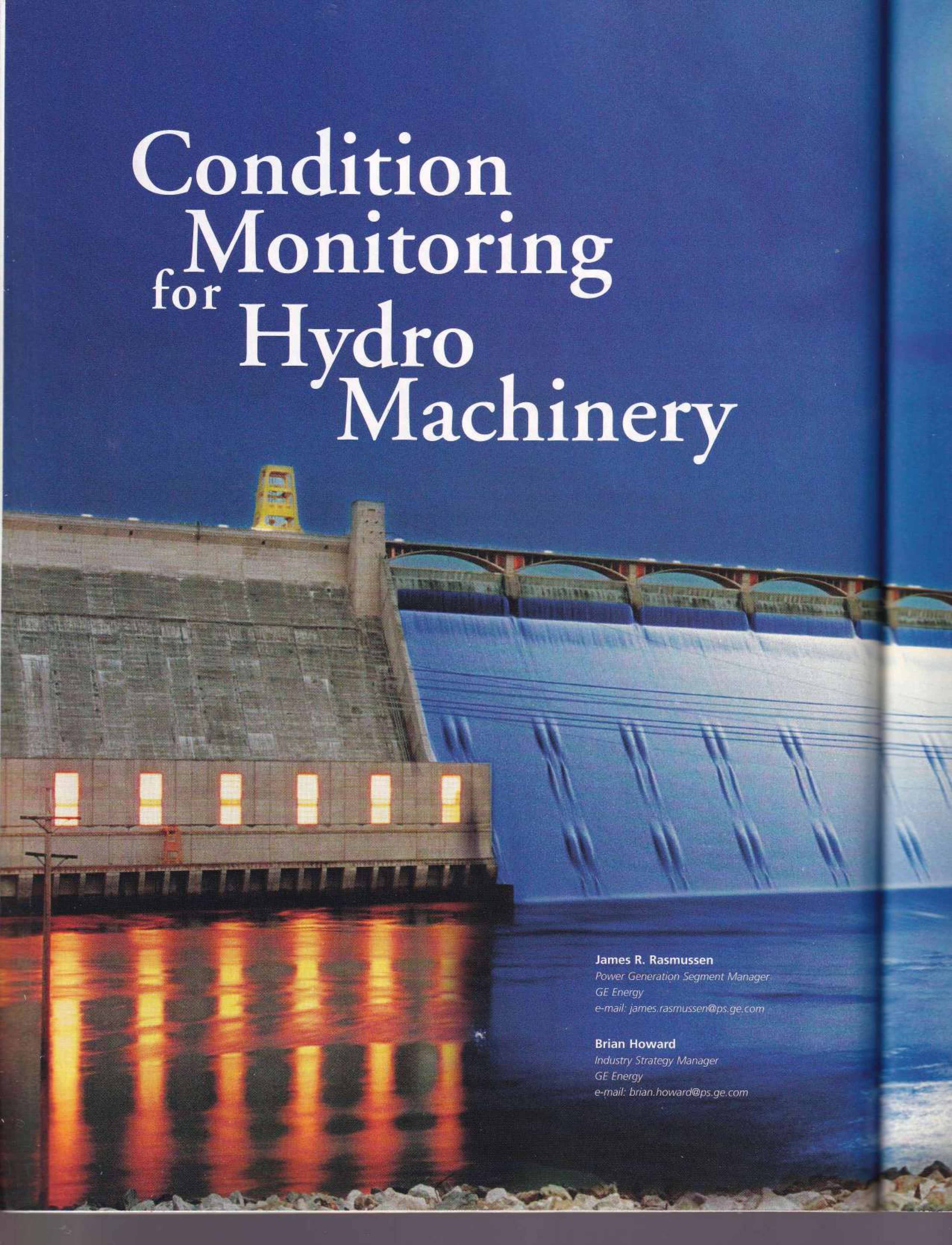
Trendmaster Pro is more than just a new name – it represents important enhancements that reduce installation and life-cycle costs, increase performance, and make it easier and more cost-effective than ever to include more assets in an online approach to condition monitoring. Bently Nevada provides not just the hardware and software elements needed for such a system, but also a broad scope of service offerings that can cover everything from economic studies that identify assets appropriate for inclusion in such a system, to planning and documenting the installation, to actually installing the system – we can even be contracted to use the system for you when your strategy is to outsource your condition monitoring activities entirely.

We encourage you to visit our website for additional information, or contact your nearest Bently Nevada sales professional.

TRENDMASTER PRO
IS MORE THAN JUST
A NEW NAME

learn more online at:
http://www.bently.com/prod/products/trendmasterpro.htm

Condition Monitoring for Hydro Machinery



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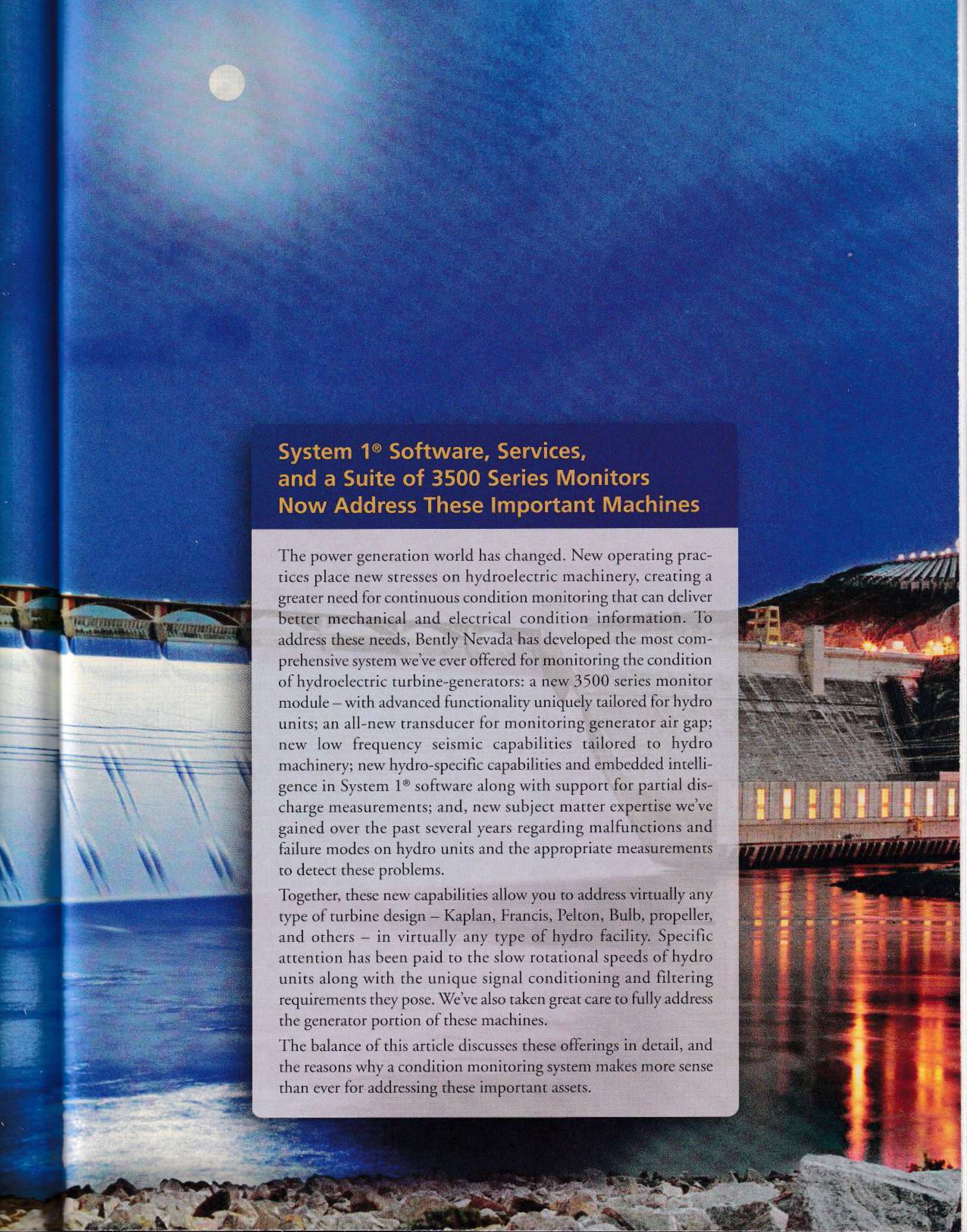


System 1® Software, Services, and a Suite of 3500 Series Monitors Now Address These Important Machines

The power generation world has changed. New operating practices place new stresses on hydroelectric machinery, creating a greater need for continuous condition monitoring that can deliver better mechanical and electrical condition information. To address these needs, Bently Nevada has developed the most comprehensive system we've ever offered for monitoring the condition of hydroelectric turbine-generators: a new 3500 series monitor module – with advanced functionality uniquely tailored for hydro units; an all-new transducer for monitoring generator air gap; new low frequency seismic capabilities tailored to hydro machinery; new hydro-specific capabilities and embedded intelligence in System 1® software along with support for partial discharge measurements; and, new subject matter expertise we've gained over the past several years regarding malfunctions and failure modes on hydro units and the appropriate measurements to detect these problems.

Together, these new capabilities allow you to address virtually any type of turbine design – Kaplan, Francis, Pelton, Bulb, propeller, and others – in virtually any type of hydro facility. Specific attention has been paid to the slow rotational speeds of hydro units along with the unique signal conditioning and filtering requirements they pose. We've also taken great care to fully address the generator portion of these machines.

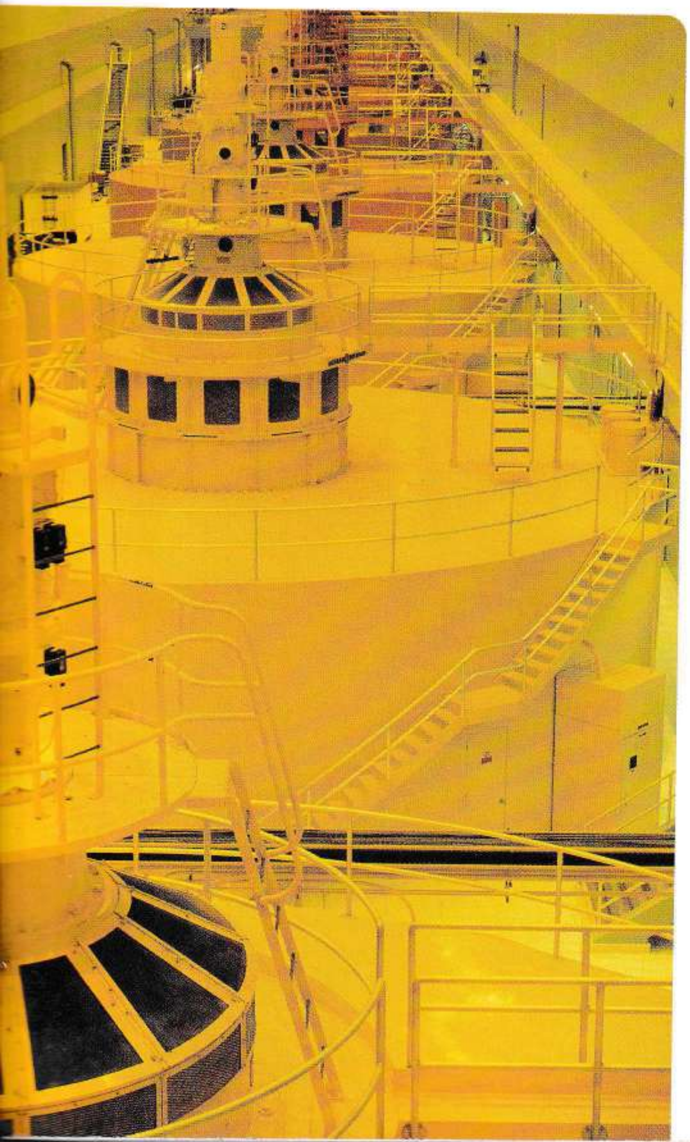
The balance of this article discusses these offerings in detail, and the reasons why a condition monitoring system makes more sense than ever for addressing these important assets.

WHY MONITORING

TABLE 1 >>

Historically, hydro machines have had the lowest cost per MW on the grid. System operators would base load these units, only reducing load or removing the units from service when maintenance was required, the power was not needed, or stream flow conditions dictated removal from service. In this base-load mode of operation, a typical large hydro machine could operate successfully for over 40 years with only routine scheduled maintenance and minimal condition monitoring.

In today's world of partially deregulated utilities and grid systems where fish and water issues often eclipse energy issues, the operating flexibility of hydro machines has led those same 40-year-old units to be the load-follow units with continuous load changes and partial load operation. In some cases, such machines are cycled on- and off-line *eight to ten times per day.* Pump/storage applications can experience even more starts and stops, often representing the most extreme operating conditions of all hydro units.



However, running a unit at partial load brings into play operational considerations like rough load zone and cavitation, along with operation that is far from the unit's peak efficiency. Further, continuous speed and load cycling introduce thermal, mechanical, and electrical stresses on the machinery that may not have even been considered in the original design. At the same time, normal scheduled maintenance outages are being reduced or eliminated.

Clearly, it's just not the same world for hydro units, and the circumstances that often allowed these units to operate virtually trouble-free for decades no longer apply. Today's operating realities are introducing a host of factors that preclude a status-quo approach to condition monitoring, maintenance, and asset management.

A properly engineered condition monitoring system can help the hydro operator avoid operating the machine in load zones where vibration or cavitation can cause premature damage. In addition, the system can provide early warning of impending failures allowing time to schedule maintenance outages and make repairs before small problems become large ones. The system will also provide the operator with sufficient information to make intelligent decisions regarding maintenance planning, thus allowing maintenance to be performed only when conditions necessitate.

WHAT MONITORING

A monitoring system for hydro turbine-generators – as for any other type of machine – must first consider the types of machinery malfunctions that must be detected and the types of machinery health information that must be supplied in order to adequately manage the asset. Table 1 summarizes this information along with the corresponding measurements required.

Table 1

Malfunctions and Corresponding Measurements

	MEASUREMENT												
MALFUNCTION[1]	Guide Bearing Vibration (Runout)[2]	Thrust Bearing Oil Film Thickness[2]	Guide Bearing Temperature[2]	Thrust Bearing Temperature[2]	Keyphasor® Pulse	Head Cover/Draft Tube Vibration	Generator Air Gap	Stator Frame Vibration	Generator Temperatures	Process Variables	Generator Partial Discharge	Wicket Gate Position	Seal Ring/Blade Tip Clearance[4]
	■ ▲ ★	■ ▲ ★	■ ▲ ★	■ ▲ ★	■ ▲ ★	▲ ★	▲ ★	▲ ★	▲ ★	▲ ★	★	★	See Note 4
Mechanical Unbalance	● (Direct, 1X)				●								
Electrical Unbalance	● (Direct, 1X)				●								
Hydraulic Unbalance	● (Direct, Shaft CL, 1X, NX)				●								
Rough Load Zone	● (NOT 1X)				●					●		●	
Shear Pin Failure	● (Shaft CL, NX)	●			●					●			
Misalignment	● (Direct, Shaft CL, 1X)				●								
Cavitation						●				●		●	
Seal Ring/ Discharge Ring Distortion[3]					●								●
Excessive Turbine Vibration[3]					●								●
Bearing Overload	●	●	●	●									
Bearing Fatigue	●	●	●	●									
Insufficient Bearing Lubrication	●	●	●	●									
Stator Insulation Deterioration											●		
Stator Winding Vibration											●		
Rotor Rim Movement					●		●						
Stator Core Shifts					●		●	●					
Uneven Air Gap					●		●	●					
Stator/Rotor Out of Round					●		●	●					
Stator/Rotor Concentricity					●		●	●					
Stator Flexing					●		●	●					
Loose Stator Laminations								●					
Unbalanced Air Gap Forces					●		●	●					
Plugged Stator Coolers									●				
Blocked Stator Ventilation Ducts									●				
Overheated Stator Coils									●				

[1] Detection of a particular malfunction requires all of the measurements checked in that row.

[2] These parameters are recommended for auto-shutdown machinery protection.

[3] Francis, Kaplan, or Propeller-type runners only.

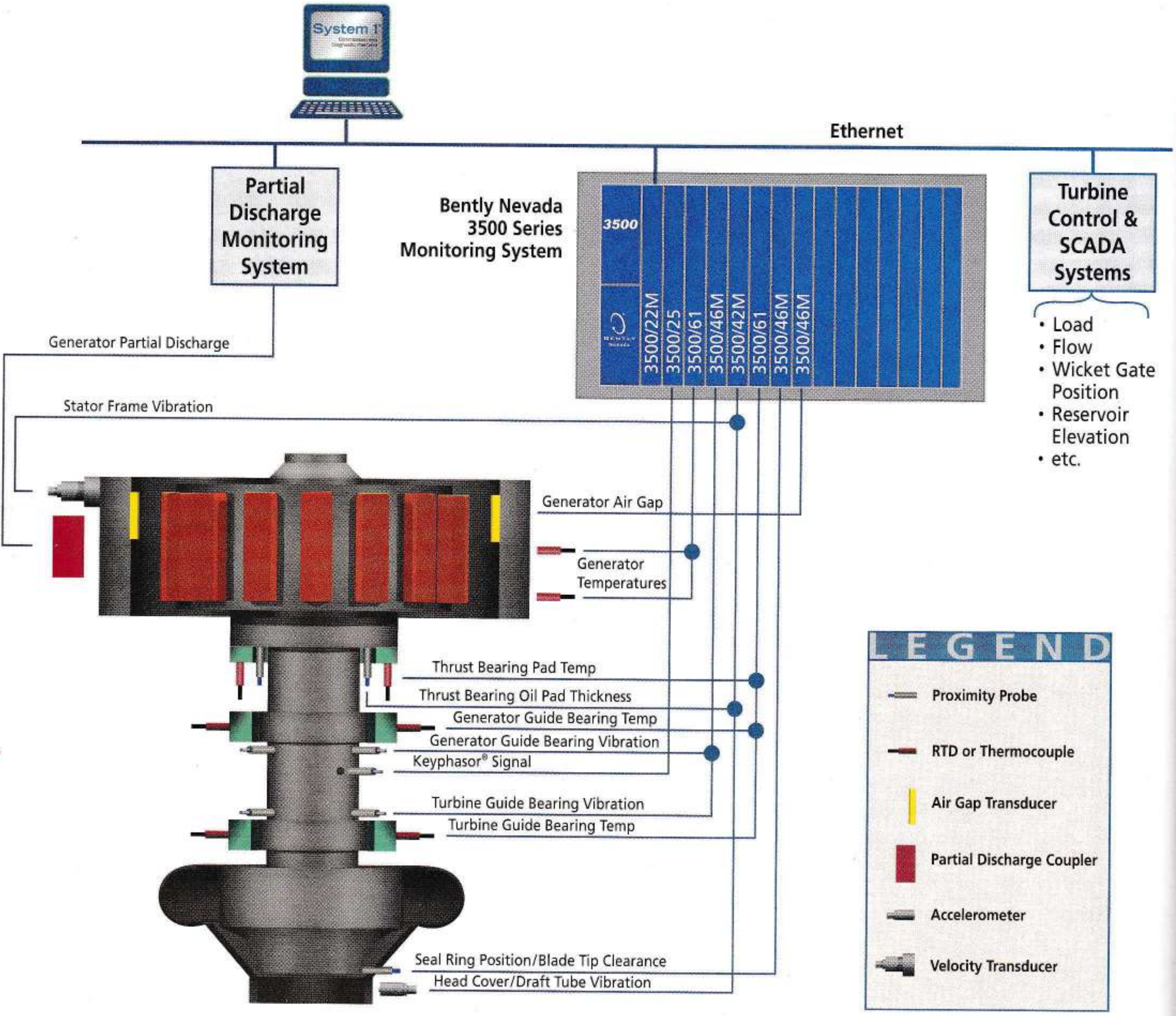
[4] This measurement is recommended on a case-by-case basis, subject to customer condition monitoring needs, equipment condition, and turbine construction constraints.

■ Minimal System – Measurements required for basic safety shutdown when catastrophic failure occurs, limited condition monitoring and proactive capabilities.

▲ Basic System – Measurements required for basic protection with moderate condition monitoring and proactive capabilities.

★ Recommended System – Measurements required for optimal protection and condition monitoring, full proactive capabilities.

FIGURE 1


System 1
Ethernet
Partial Discharge Monitoring System
Bently Nevada 3500 Series Monitoring System
3500
3500/22M
3500/25
3500/61
3500/46M
3500/42M
3500/61
3500/46M
3500/46M
Turbine Control & SCADA Systems
• Load
• Flow
• Wicket Gate Position
• Reservoir Elevation
• etc.
Generator Partial Discharge
Stator Frame Vibration
Generator Air Gap
Generator Temperatures
Thrust Bearing Pad Temp
Thrust Bearing Oil Pad Thickness
Generator Guide Bearing Temp
Generator Guide Bearing Vibration
Keyphasor® Signal
Turbine Guide Bearing Vibration
Turbine Guide Bearing Temp
Seal Ring Position/Blade Tip Clearance
Head Cover/Draft Tube Vibration
LEGEND
Proximity Probe
RTD or Thermocouple
Air Gap Transducer
Partial Discharge Coupler
Accelerometer
Velocity Transducer

HOW MONITORING

For each of the measurements in Table 1, Bently Nevada can now provide an integrated monitoring solution that is fully compatible with System 1 software. Table 2 on the following page summarizes the appropriate transducers and monitoring modules; Figure 1 at left shows the arrangement of these transducers on a typical vertical unit.

3500/46M Hydro Monitor

Hydroelectric turbine-generators are subject to forces and operating conditions unique to their operation and configuration. They typically operate at low rotational speeds, usually from 60 to 600 rpm, and are physically very large, often with generator rotors that may be more than 50 feet in diameter and weigh more than 1,000 tons. Their physical mass and slow rotational speeds give rise to large vibration amplitudes and low vibration frequencies. This requires a monitoring system with special low frequency response capabilities.

In addition, many of the vibration behaviors typical to these machines require specialized filtering and signal conditioning. For example, rough load zone is known to generate vibration at sub-harmonic frequencies. By monitoring the overall vibration amplitude minus the 1X component, a parameter called NOT 1X is derived; it is a reliable indicator of rough load zone. Shear pin failures and wicket gate problems are known to generate primarily super-harmonic frequencies, known as NX frequencies, that are multiples of turbine running speed. By monitoring NX and a derived measurement (known as Composite) which consists of both gap voltage and NX amplitude, these faults can be detected. Various forms of electrical, hydraulic, and mechanical unbalance manifest themselves primarily as 1X vibration. Many other problems show up as simply an increase in overall vibration amplitude.

To address these specialized filtering, signal processing, and frequency response requirements, Bently Nevada has developed the 3500/46M Hydro Monitor module. A 4-channel monitor, channels can be configured for either air gap measurements or radial vibration measurements, simultaneously processing the input signal for each channel, depending on configuration, as follows:

RADIAL VIBRATION (Guide Bearings, Seal Ring Position, Blade Tip Clearance)	GENERATOR AIR GAP
• Overall vibration (direct) • 1X filtered vibration and phase • NX filtered vibration and phase (where N is a user-selectable integer between 2 and 20) • NOT 1X vibration amplitude • Gap voltage (shaft radial position) • Composite	• Instantaneous air gap • Average air gap • Minimum air gap • Maximum air gap • Minimum air gap pole number • Maximum air gap pole number

Users can establish Alert and Danger alarming on many of these parameters, and the monitor is fully compatible with System 1 software, allowing a variety of hydro-specific plots to be generated such as air gap versus pole, rotor shape, and combined rotor/stator shape for roundness and concentricity.

TABLE 2

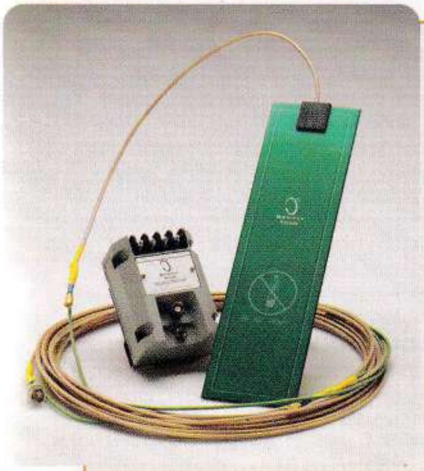
MEASUREMENT	MONITOR	TRANSDUCER
Guide Bearing Vibration (Runout) By measuring vibration at generator and turbine guide bearings, a variety of important malfunctions can be detected such as rough load zone*, various sources of unbalance, shear pin failure, bearing problems, and wicket gate problems. Each channel of the 3500/46M module can simultaneously monitor direct, 1X vector, NX vector, NOT 1X, shaft radial position (gap voltage), and composite amplitude (gap voltage change multiplied by NX amplitude). This special signal conditioning and filtering is required for detecting various malfunctions.	3500/46M 4-channel Hydro Monitor	3300 XL Series Proximity Transducer Targeting the Machine Shaft X-Y configuration at each bearing.
Thrust Bearing Oil Film Thickness Large vertical hydro units can weigh over 1,000 tons, with the unit's entire weight carried by the thrust bearing. An absence or reduction in oil film thickness at the thrust pads results in rapid breakdown of the bearing babbit and can result in rotor/bearing damage if not corrected. On hydro units, the thrust bearing shoes are fitted with proximity probes observing the thrust collar, providing a measurement of oil film thickness.	3500/40M or 3500/42M 4-channel Vibration / Position Monitor	3300 XL Series Proximity Transducer One probe each in two selected pads, with approximately 90 degrees of radial separation. For units larger than 100 MW, four probes (one every 90 degrees) are generally advised.
Guide Bearing Temperatures Bearing temperature can indicate problems related to fluid-film bearings, including overload, bearing fatigue, or insufficient lubrication.	3500/61 6-channel Temperature Monitor	RTD or Thermocouple One sensor per bearing pad.
Thrust Bearing Temperatures Bearing temperature can indicate problems related to fluid-film bearings, including overload, bearing fatigue, or insufficient lubrication.	3500/61 6-channel Temperature Monitor	RTD or Thermocouple One sensor per bearing shoe.
Keyphasor® Signal A proximity probe observing a once-per-turn notch or protrusion (such as a key or keyway) on the machine's shaft provides a precise reference signal used for indicating rotational speed, filtering vibration to multiples of running speed (such as 1X, NX, and NOT 1X), providing vibration phase information, and allowing air gap profile data. The Keyphasor signal is required by the 3500/46M and other monitor modules.	3500/25 Keyphasor® Module	3300 XL Series Proximity Transducer Generally mounted near the upper guide bearing. The shaft's notch or projection should align with an established reference on the rotor such as the generator's #1 pole.
Head Cover/Draft Tube Vibration Certain operating conditions can give rise to cavitation, an implosion of vapor cavities in the liquid. Cavitation can damage the turbine, eroding metal, affecting efficiency, and eventually forcing a shutdown and dewatering for repair of affected parts. Cavitation is measured with an accelerometer mounted on the draft tube or the turbine head cover. By monitoring for draft tube or head cover vibration with an accelerometer, and filtering appropriately, cavitation can be detected and conditions can be adjusted to avoid operating the unit in this damaging region.	3500/42M 4-channel Proximitor® / Seismic Monitor	330425 Accelerometer
Generator Air Gap Special capacitive sensors mounted around the bore of the stator measure the distance between the rotating and stationary parts in the generator. Air gap measurement is important because the stator is a flexible assembly that can become distorted or off center. The monitor is able to provide instantaneous, minimum, maximum, and average air gap measurements along with the rotor pole to which min and max measurements coincide. When connected to System 1, the software can interpolate between sensors, providing calculated stator shape plots.	3500/46M 4-channel Hydro Monitor	4000 Series Air Gap Sensor Four sensors per stator when bore diameter is less than 7.5m; eight sensors when bore exceeds 7.5m; 12-16 sensors when bore exceeds 12m.
Stator Frame Vibration Vibration of the stator core and frame can cause fretting and damage to the winding insulation. Uneven air gap can also cause the stator core to vibrate. By mounting an appropriate seismic vibration transducer on the stator core/frame, such problems can be detected before serious damage occurs.	3500/42M 4-channel Proximitor® / Seismic Monitor	Low-frequency seismic transducers mounted on the outer diameter of the stator core and frame.
Generator Temperatures Temperature sensors are installed in locations such as in stator slots, air cooler inlet and outlet, water inlet and outlet, etc., providing important information on stator condition. The monitor provides alarming functions, alerting operators when temperatures are outside of acceptable limits. The monitor can also supply temperature information to System 1 software where it can be trended and correlated with other measurements for a more complete picture of unit health.	3500/61 6-channel Temperature Monitor	RTD or Thermocouple

** A United States patent is pending for detection of rough load zone operation.*

Table 2 (continued)

MEASUREMENT	MONITOR	TRANSDUCER
Process Variables Load, reactive load, exciter voltage and current, generator voltage and current, lube oil pressure, wicket gate position, and reservoir elevation are just a few of the parameters that may be available in the unit's or plant's control and automation system, and these variables can generally be easily interfaced to System 1 software. However, in some cases a process-related measurement is either not available in the unit's control system, or it is simply beneficial to hardwire the signal in parallel to both the control system and the condition monitoring system. Unit load is a particularly important parameter that should be included in the condition monitoring system whenever possible.	3500/62 6-channel Process Variable Monitor	Any sensor with an industry-standard proportional output of 4-20 mA, 1-5 Vdc, or any proportional voltage between –10 and +10 Vdc
Generator Partial Discharge Partial discharges are the small electrical sparks that occur within the voids of high-voltage insulation systems. By monitoring these partial discharges, a variety of winding-related problems can be detected, allowing maintenance to be planned and serious failures to be avoided.	Continuous PD monitor (provided by third party).	Capacitive PD Couplers
Wicket Gate Position Monitoring wicket gate position provides an indication of turbine flow. Combined with other parameters such guide bearing vibration, reservoir elevation, and load, flow-induced instabilities at the turbine runner can be identified and avoided. Wicket Gate position is often included in the unit's control system and can be monitored directly with System 1. If wicket gate position is not monitored, an LVDT can be used to make the measurement.	3500/45 4-channel Position Monitor	Linear Variable Differential Transducer (LVDT)
Seal Ring Position/Blade Tip Clearance Francis-, Kaplan-, and propeller-type turbines employ seal rings to prevent unwanted leakage of water past the runner, influencing efficiency. Francis units have two rings – a stationary ring and a rotating ring mounted on the runner. In contrast, Kaplan and propeller units have only a stationary ring that seals directly against the rotating blade tips. Mounted at the extremity of the unsupported portion of the shaft, these sealing surfaces are subject to rubbing when extreme shaft deflection occurs. On pump/storage units, such deflections can be common during pump-mode startup.	3500/46M 4-channel Hydro Monitor	3300 XL Series 11mm Proximity Transducer, modified for underwater use and runner target material.

(continued on page 56)



An All-New Air Gap Sensor System

Air gap is a measure of the distance between rotor and stator in the hydro generator. On-line monitoring of air gap is important because both the stator and the rotor on large hydro machines can be quite flexible, and their shape and location are affected by operating centrifugal, thermal, and magnetic forces.

Off-center or out-of-round conditions will, at minimum, reduce operating efficiency. More severe cases can lead to damage from magnetically induced heating or a rotor-to-stator rub.

Air gap monitoring utilizes multiple specially designed capacitive proximity sensors that are mounted on the inner bore of the generator stator in one or more planes. Measurements are made from the stator bore to each rotor pole as the rotor turns. Minimum air gap dimension and location along with rotor shape are directly measured during unit operation. Stator shape is calculated utilizing multiple air gap transducers.

Air gap measurements are made using Bently Nevada's 4000 Series Air Gap Sensor System and the 3500/46M monitor. Its unique design has a United States patent pending, and it incorporates many of the robust design features found in our eddy-current proximity probes used for vibration and position measurements, ensuring long, trouble-free service. Special focus has been placed on making the product easy to install, immune to installation-related performance variation, and robust for years of trouble free service.

To learn more, download the product datasheet from www.bently.com, or consult your nearest Bently Nevada sales professional.

(continued from page 55)

System 1® Software – An Optimization and Diagnostics Platform

By adding condition monitoring and diagnostics software to the hydro monitoring hardware, customers can take an important step forward in their ability to proactively manage their hydro units.

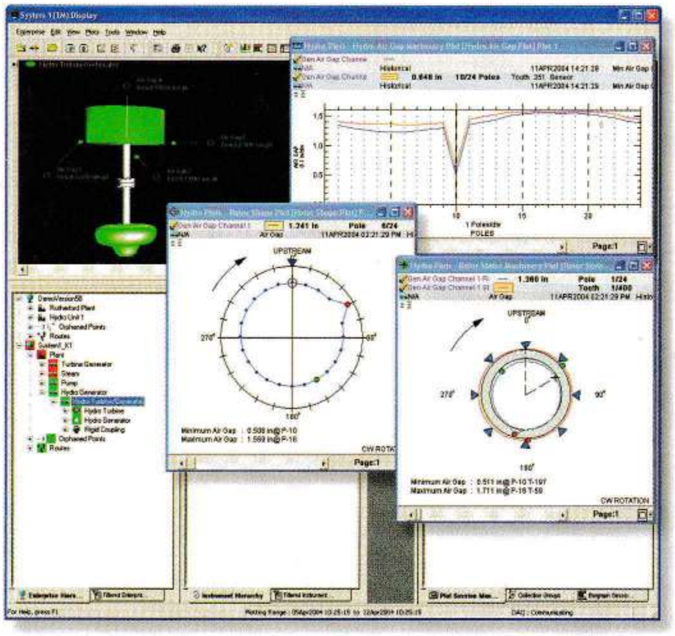
System 1 is a platform for managing every asset in your plant. In addition to its condition monitoring capabilities, System 1 links to maintenance management applications, reliability tools, process control, SCADA, historian systems, diverse documentation resources, and much more. This integration of multiple systems is a significant advantage to hydro customers, allowing them to monitor and trend parameters from diverse systems in a single user interface. And – as we'll discuss in the section on Decision Support – System 1 not only displays data, it *analyzes* data.

System 1 now includes powerful capabilities specifically for addressing the unique needs of hydroelectric turbine-generators. The result is a total hydro asset management solution capable of providing:

- Bearing babbit and oil temperature
- Air Gap
- Generator Stator Temperature
- Cavitation
- Seal Ring Clearance
- All available process variables
- Generator Partial Discharge
- Vibration monitoring over the entire operating frequency range
- Thrust bearing oil film thickness
- Stator core and frame vibration
- Wicket Gate Position
- Turbine flow monitoring

System 1 software allows you to analyze, trend, correlate, and display vibration, position, temperature, and any other variable of interest. A wide variety of plot types are available with relevance to hydro operators, a few of which are summarized in Table 3.

TABLE 3 >>



System 1 software features a vriety of new plot types specifically for hydro units.

NEW HYDRO-SPECIFIC PLOT TYPES IN SYSTEM 1	
OVERALL HYDRO PLANT VIEW	Displays an overview of plant condition with normal parameters in green and alarm parameters in colors designating severity of the alarm.
AIR GAP PLOTS (GAP VERSUS POLE)	Displays the gap for each sensor versus pole number, for one rotor revolution.
AIR GAP PLOTS (ROTOR SHAPE)	Displays measured rotor shape as observed from each air gap probe.
AIR GAP PLOTS (COMBINED ROTOR AND STATOR SHAPE)	Displays stator and rotor roundness and concentricity by combining measured rotor shape with calculated stator shape.
X VERSUS Y	Plotting any X (such as vibration) versus any Y (such as unit load), provides powerful diagnostic tools. Cause-and-effect relationships and correlation can be easily visualized and understood. System 1 has data historian capabilities allowing it to archive virtually any data, even if not condition-related. It can also interface to existing historian systems you may already have installed.
MULTI-PARAMETER PLOTS	Multiple parameters can be displayed on the same plot. For example, plotting turbine flow, combined unit load, and bearing vibration provides the ability to immediately identify events associated with rough load zone. Changes in the duration and amplitude of these events can be an indication of excessive wear or impending failure.

Decision Support℠

A key aspect of asset management is the ability to detect asset-related symptoms and events as early as possible and with as much clarity as possible. This is where System 1 provides exceptional capabilities. In addition to System 1's powerful plotting, trending, and manual data analysis functionality is its Decision Support functionality. Decision Support is System 1's ability to automatically validate and analyze its collected data using user-configurable rules and knowledge; detect mechanical, electrical, or hydrodynamic problems; and generate informative Actionable Information® advisories.

Let's say that you want to customize the system with special rules reflecting a known set of conditions that, through experience, you've found always indicate a need for maintenance and are unique to a particular unit. For example, you have found that an increase in vibration at NX (where N is the number of wicket gates and X is operating speed) combined with a change in the rotor shaft position (lower guide bearing gap) and shaft orbit is an indication of a broken wicket gate shear pin.

When System 1 detects these three parameter changes based on your custom criteria, you might have multiple people in the plant that you want to notify. A different event notification message (with content completely customized to the recipient – even their name and phone number!) can be sent to each individual, with any severity you determine, using any of System 1's notification mediums (process control system alarm, e-mail, cell phone, PDA, pager, desktop software notifier, etc.).

System 1 RulePaks

We have also introduced a series of pre-configured rule collections – RulePaks – for specific machine types. In fact, a hydro-specific RulePak is currently in development. RulePaks can be loaded directly into the Decision Support module of System 1, giving you ready-made capabilities to automatically isolate and identify numerous common problems for specific machine types or even machine components, without the need to write your own rules.

RulePaks can also be combined with the rules you have authored yourself using Decision Support Studio, giving you a system tailored to your exact needs. Armed with these Decision Support capabilities, your company's ability to make faster, more confident operating and maintenance decisions is easier than ever.

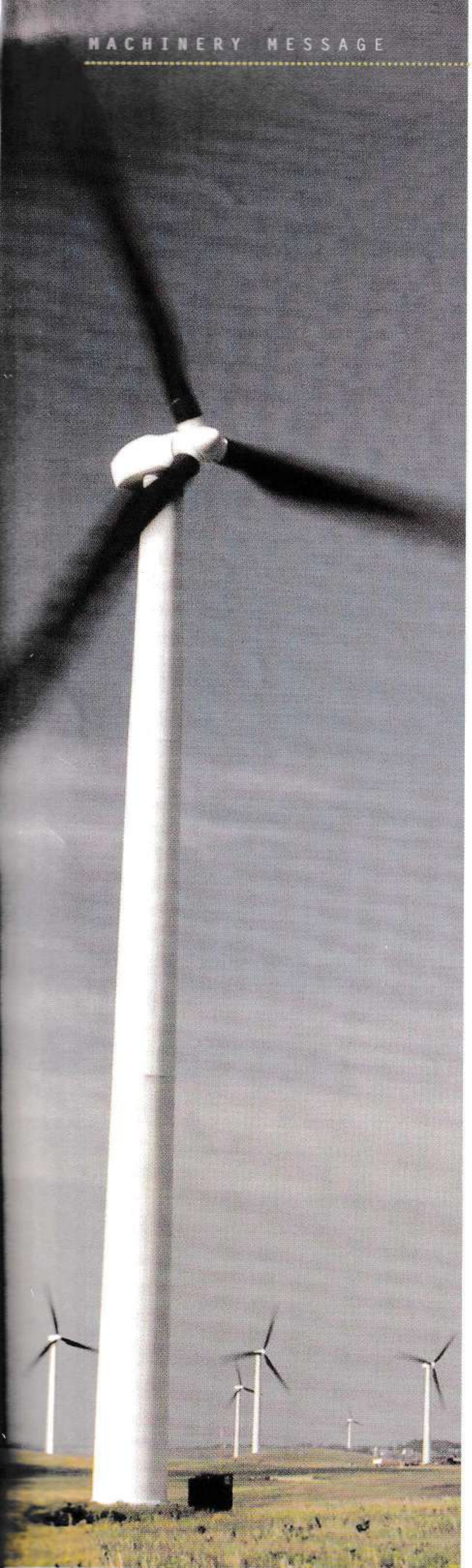
Services – From Turnkey to Do-It-Yourself

Every customer is different. Some prefer to monitor their machines themselves and install the systems themselves. Others want help with installation, but not with the actual use of the system to perform machinery diagnostics. Still others may require occasional help with balancing or alignment, but little else. Whatever your needs, Bently Nevada is pleased to offer a comprehensive portfolio of services for hydro units, including:

- Monitoring system design, site installation, site project management, and full system documentation (both new machines and retrofits)
- System integration to ensure your condition monitoring system can interchange data and information with process control, SCADA, maintenance management, reliability management, and other pertinent systems
- Balancing and alignment
- Training – for both machinery diagnostic fundamentals and operation/maintenance of monitoring system instrumentation
- Reliability Services including Opportunity/Risk Assessment
- Lubrication consulting/management
- Foundation/footing problems
- Remote or onsite machinery diagnostics
- Condition monitoring program management
- Support for all Bently Nevada and selected other instrumentation and software solutions

Summary

Many of today's hydro units are operating under conditions that introduce significant mechanical and electrical stress on the assets – stresses that were often not even envisioned when the machines were designed, and stresses that are a direct result of new realities in the power market that require tremendous operational flexibility. Never before has the need for comprehensive condition monitoring on hydro units been more important, and Bently Nevada can now offer the hardware, software, and services to fully address these important assets. New transducers, new 3500 Series monitoring modules, new capabilities in System 1 software, and newly expanded service offerings – all designed to meet the unique needs of our hydro customers. For more information, contact your nearest Bently Nevada sales professional, or visit us on the Web at www.bently.com.



Improved Wind Turbine Condition Monitoring Using Acceleration Enveloping

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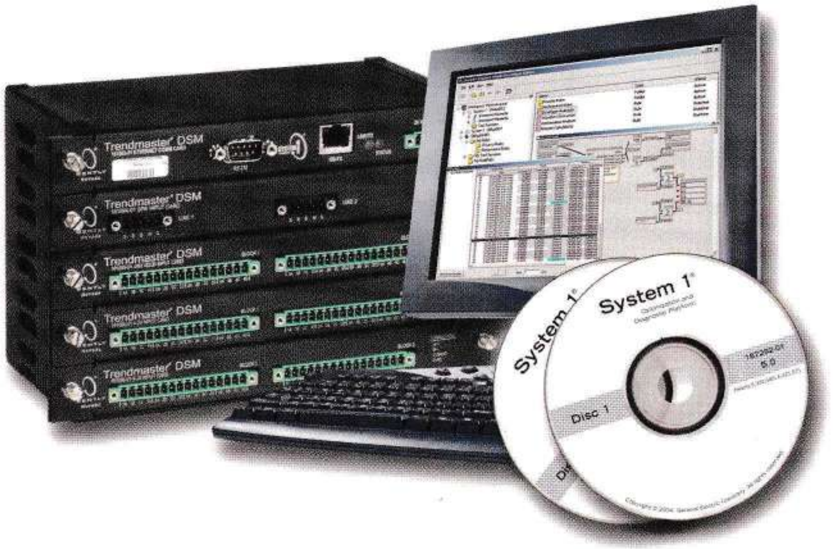
Wind turbines are becoming more established as an economically viable alternative to fossil-fueled power generation. Wind farms consisting of hundreds of units are now adding a significant amount of electrical generating capacity around the world. As the size of wind farms continues to increase, business economics dictate careful asset management to minimize downtime and maximize availability and profits. To help customers more proactively detect mechanical problems on these important machines, Bently Nevada has introduced both permanently mounted and portable offerings for wind turbine monitoring. The permanently mounted offering is based on our Trendmaster® Pro distributed condition monitoring architecture (read more about this system on page 30). The portable offerings are from our Snapshot™ family of data collectors/analyzers. Integral to both the Trendmaster Pro and Snapshot offerings is a signal processing technology known as acceleration enveloping, which can be particularly beneficial when applied to wind turbines. The remainder of this article explores the technology and its benefits in more detail, specifically as they relate to wind turbines.



The Wind Turbine

Wind turbines are complex machines that convert the energy of moving air to electrical power. Extraction of a significant amount of energy requires a large turbine diameter; thus, turbine speeds are slow, and the speed must be increased to a useful generator speed. A typical wind machine has a 3-blade turbine more than 60 meters in diameter, turning around 20 rpm. This turbine drives a generator through a speed-increasing gearbox that generally has a planetary first stage and one or two additional parallel shaft stages. The generator runs at about 1500 rpm and produces about 1.5 MW. Many wind turbines are variable speed machines; the speed depends on the wind conditions and can vary over a wide range.

For these machines, high power output requires high levels of torque and accompanying high gear-mesh forces. Because of the low speed of the turbine, the various gearbox components are usually supported by rolling element bearings. These bearings are subject to significant radial loads and need to be carefully monitored to detect any degradation.

Vibration Instrumentation

Typically, wind turbines are instrumented with one or more externally mounted accelerometers or velocity transducers and at least one Keyphasor® probe, which provides a once-per-turn speed reference. Direct vibration is usually monitored, and frequency analysis can be added.

There are two primary groups of vibration frequencies in a wind turbine: gear mesh frequencies and bearing defect frequencies. In one typical machine, there are three fundamental gear mesh frequencies (and their harmonics) that result from the meshing of a sun gear, planets, a ring gear, and two other pinions and gears. There are several shafts supported by many bearings, each of which produces a set of four defect frequencies (outer race ball pass, inner race ball pass, cage, and element spin). It is easy to see that the combination of mesh frequencies, harmonics, and bearing defect frequencies can make frequency analysis a formidable task.

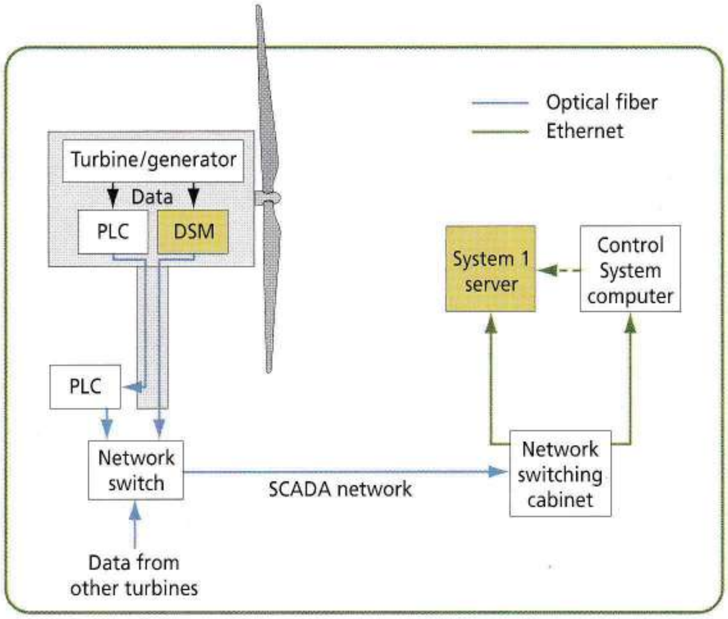
Acceleration Enveloping

Enveloping can have high sensitivity to faults that produce impacting, and it can help reduce the complexity of the analysis. Rolling element bearing defects fall into this impact category. A spall in a race or element will cause repeated impact events that excite structural natural frequencies. These natural frequencies "amplify" the vibration resulting from the impact and make it easier to detect. Because enveloping depends on the presence of higher frequency structural vibration, accelerometers are typically used to detect the vibration; hence the common name – acceleration enveloping.

In the enveloping process, the raw accelerometer waveform is first high-pass (or band-pass) filtered, then rectified, enveloped, and processed through an FFT algorithm. The resulting envelope spectrum reveals the defect repetition frequencies, which can then be compared to known bearing defect frequencies.

Wind Turbine Test

How well does enveloping work in a wind turbine application? To answer this question, Bently Nevada conducted a test as part of our product development effort in this technology. We instrumented several wind turbines with accelerometers and a Keyphasor probe. For this test, several accelerometers were mounted at various places on the gearbox. The Keyphasor probe provided an output shaft speed reference.



THE DATA ACQUISITION SYSTEM. TRANSDUCER SIGNALS COLLECTED BY THE DYNAMIC SCANNING MODULE (DSM) WERE PASSED THROUGH THE SCADA NETWORK TO THE SYSTEM 1® SERVER. AN ADDITIONAL LINK FROM THE CONTROL SYSTEM COMPUTER TO SYSTEM 1 ALLOWS COLLECTION OF DATA ON POWER; TORQUE; GEARBOX, GENERATOR, AND AMBIENT TEMPERATURES; BLADE ANGLE; AND WIND SPEED.

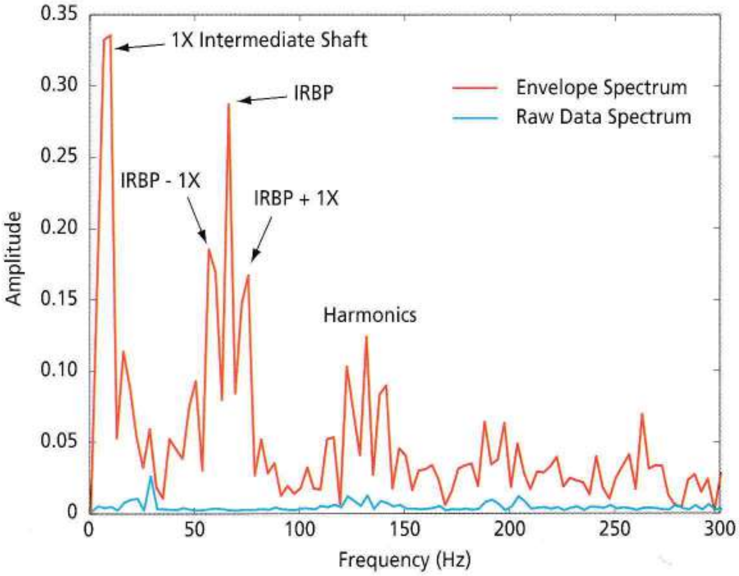
FIG. 1

A Trendmaster® Pro Online Condition Monitoring System equipped with a Trendmaster Dynamic Scanning Module (DSM) passed the data through the Supervisory Control and Data Acquisition (SCADA) network to System 1® condition monitoring software (Figure 1). System 1 archived the data for future reference, and the data was postprocessed and enveloped using a proprietary algorithm.

After analysis, it was immediately apparent that one machine had a serious problem with one of the gearbox bearings. The machine was shut down, and the bearing was replaced. After restarting the unit, data was collected from the repaired machine and analyzed to provide a comparison.

Results

Figure 2 shows the raw acceleration signal spectrum (blue) and the envelope spectrum (red) of the output shaft accelerometer data from the machine with the damaged bearing. The data demonstrates the much higher sensitivity of enveloping to bearing defect frequencies. In the envelope spectrum, the lowest prominent frequency near 8 Hz corresponds to the rotation speed of the gearbox intermediate shaft. The next feature (66 Hz) is the



THIS DATA FROM THE MACHINE WITH THE DAMAGED BEARING DEMONSTRATES THE MUCH HIGHER SENSITIVITY OF ENVELOPING TO BEARING DEFECT FREQUENCIES. THE RAW ACCELERATION SIGNAL SPECTRUM (BLUE) AND IS COMPARED TO THE ENVELOPE SPECTRUM (RED) OF THE OUTPUT SHAFT ACCELEROMETER DATA.

FIG. 2

inner race ball pass (IRBP) frequency of one of the intermediate shaft bearings. It has two sidebands that are located at 8 Hz to either side of the 66 Hz frequency. The next cluster of frequency lines centered near 132 Hz represents harmonics of the group around 66 Hz. These harmonics are an artifact of the enveloping algorithm and have no physical meaning.

The bearing was removed and inspected, and substantial damage was found on the inner race. Figure 3 shows one of several large spalls that were found on this race.

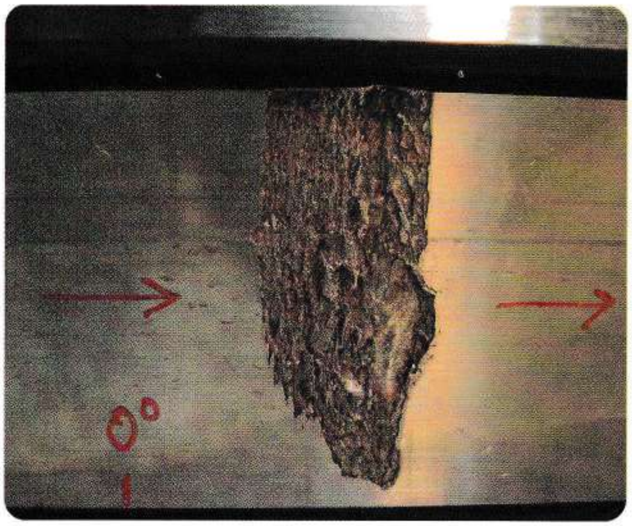
The bearing was replaced, and the wind turbine was returned to service. Data was collected again and processed as before. Figure 4 compares the raw acceleration signal spectrum (blue) with the envelope spectrum (red) from the same accelerometer as in Figure 2. The spectrum of the raw accelerometer data shows some gear mesh frequencies, but the envelope spectrum is completely clean.

Conclusions

While the raw spectrum can be useful for monitoring gear mesh frequencies, the envelope spectrum provides superior sensitivity to bearing defect frequencies in wind turbine applications. The chief advantage of enveloping is that it provides excellent visibility of bearing defect frequencies without the visual interference of gear mesh frequencies in the same spectrum. This effect can be seen in both Figures 2 and 4, where gear mesh frequencies are present in the raw signal spectra but are absent in the envelope spectra. This occurs because gear meshing is a relatively smooth process and produces little impact energy. The gear mesh frequencies are removed during the first high-pass filtering of the raw data.

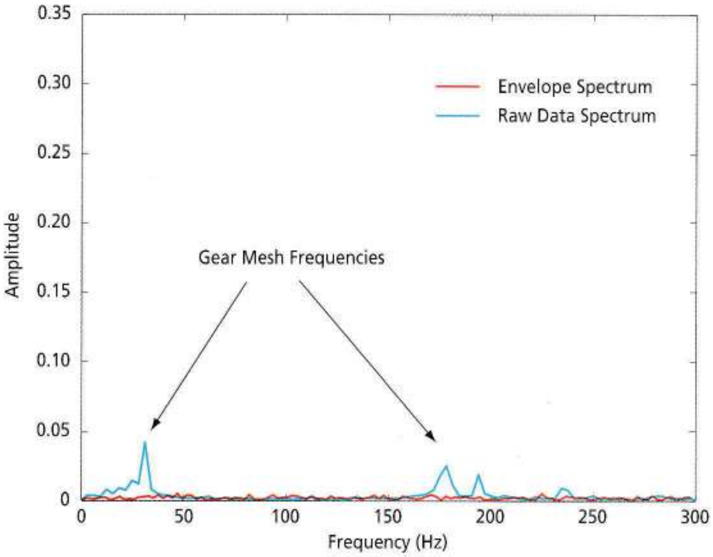
Enveloping thus provides a powerful tool for monitoring wind turbine bearings. It is now included in our Trendmaster Pro System (see companion article on page 20) as well as our Snapshot™ family of portable data collection instruments. The result is enhanced capabilities for more proactive detection of mechanical problems on these important machines.

Editor's Note: You can read more about acceleration enveloping on page 10 in this issue of ORBIT.



DAMAGE ON THE INNER RACE OF ONE OF THE INTERMEDIATE SHAFT SUPPORT BEARINGS. THIS WAS ONE OF SEVERAL SPALLS IN THE BEARING.

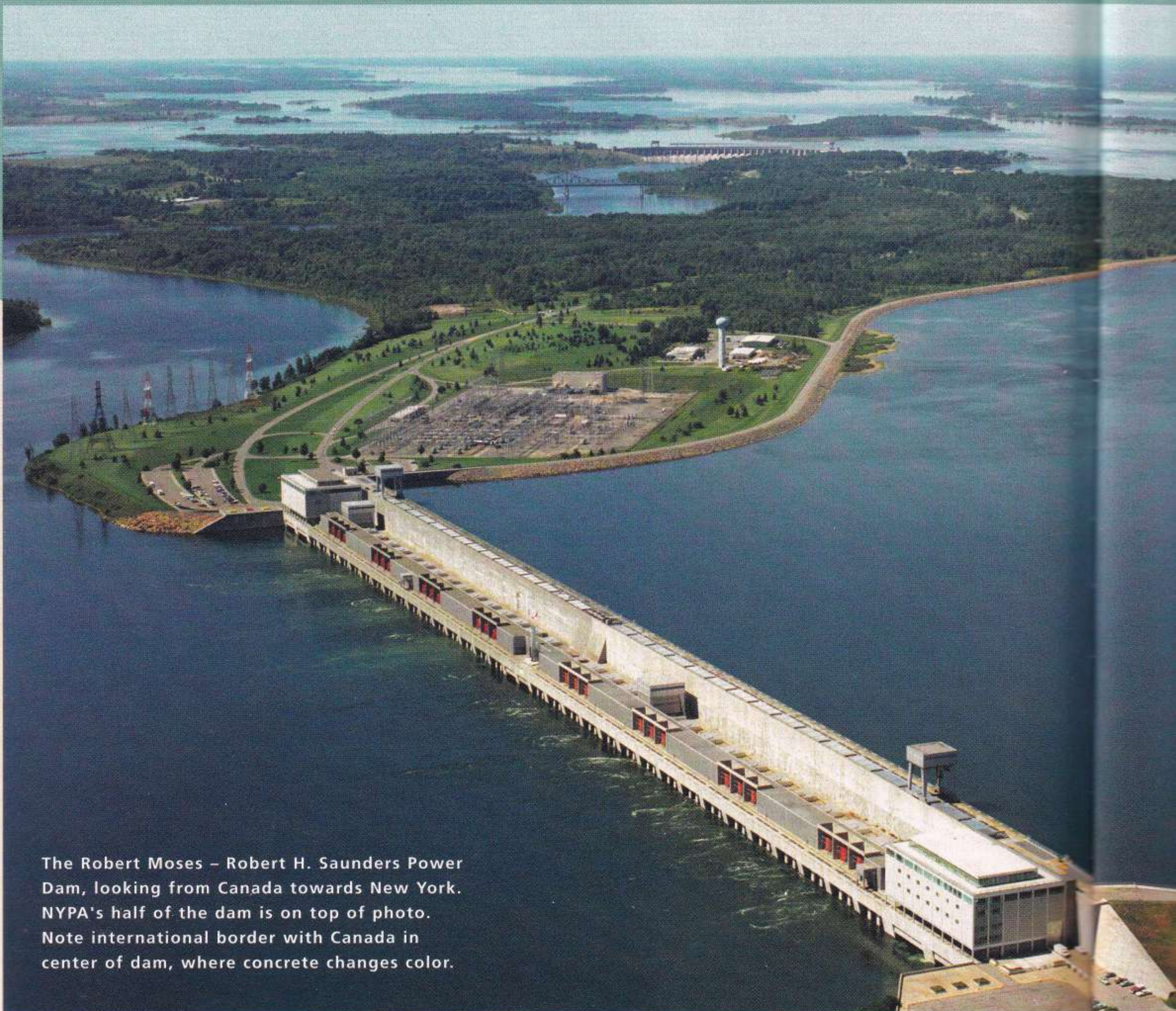
FIG. 3



THE ENVELOPE SPECTRUM FROM THE MACHINE WITH THE NEW BEARING SHOWS NO BEARING DEFECT FREQUENCIES. THE RAW ACCELERATION SIGNAL SPECTRUM (BLUE) IS COMPARED TO THE ENVELOPE SPECTRUM (RED) OF THE OUTPUT SHAFT ACCELEROMETER DATA. SEE ALSO FIGURE 2.

| FIG. 4

The HydroX™ System



The Robert Moses – Robert H. Saunders Power Dam, looking from Canada towards New York. NYPA's half of the dam is on top of photo. Note international border with Canada in center of dam, where concrete changes color.

Built on System 1® Technology, NYPA's Vision for Proactive Asset Management Becomes Reality

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Introduction

The New York Power Authority (NYPA) is America's largest state-owned electric utility, operating 17 generation facilities and over 1,400 circuit-miles of transmission lines. It is also New York's only statewide electricity supplier. With a history dating back to 1931 when then-governor Franklin D. Roosevelt signed the Power Authority Act into law, NYPA has since been providing some of the lowest-cost electricity in New York State. NYPA is a non-profit, public-benefit corporation that does not use any tax revenues or state credit.

Competition in the electric utility industry continues to increase, demanding operational excellence while maintaining generation and transmission facilities safely, reliably, and economically. A significant NYPA initiative in pursuit of these goals is the transition from preventive maintenance (maintenance at fixed calendar intervals) to condition-based maintenance (CBM) (maintenance based on observed electrical/mechanical parameters). CBM has proven to reduce operating and maintenance costs, extend machine life, and reduce forced outages.

A REFURBISHED TURBINE RUNNER ARRIVES AT SITE AS PART OF NYPA'S LIFE EXTENSION AND MODERNIZATION (LEM) PROJECT.

To enable this transition, NYPA has undertaken a project targeting their hydro turbine-generator assets with a continuous condition monitoring system that employs embedded expert diagnostic capabilities. The system – called HydroX™ (for Hydro Expert) by NYPA – is very ambitious. Its function is to bring together the dozens of various condition and process-related measurements on a typical unit, embed the diagnostic expertise of NYPA and other subject matter experts in a common software platform, use this software platform to perform automated diagnostics, and generate advisories to plant personnel on unit health.

This article explores NYPA's vision for the HydroX system in more detail, summarizing the challenges faced, the choice of suppliers and technologies to make the HydroX system a reality, and future plans.

The HydroX Vision

NYPA's vision for the HydroX system is straightforward: to continuously and automatically evaluate the operational performance of hydro turbine-generators and assess changes in various machine parameters as measured by standard and special-purpose sensors.

To enable such capabilities, NYPA wanted a system capable of employing advanced heuristic and probabilistic methods to analyze the continuously collected data. These methods would be able to automatically detect the onset of failure-causing degradation, allowing cost-effective corrective action to be planned.

The HydroX Challenge

Because the measurements for the HydroX system come from a diversity of sources and manufacturers, ranging from generator control systems to partial discharge monitoring systems to vibration monitoring systems, finding a common software platform that links these all together while meeting NYPA's requirements was not easy. The system needed to be capable of not just conventional data acquisition functions, but automated data analysis as well, employing highly customizable "expert system" capabilities.

Initially, NYPA assumed that they would have to develop their own "home-grown" package and work began towards this end in 2000. Although a custom-built application was not NYPA's ideal solution, they did not perceive that an off-the-shelf solution existed with their required functionality.

The Players

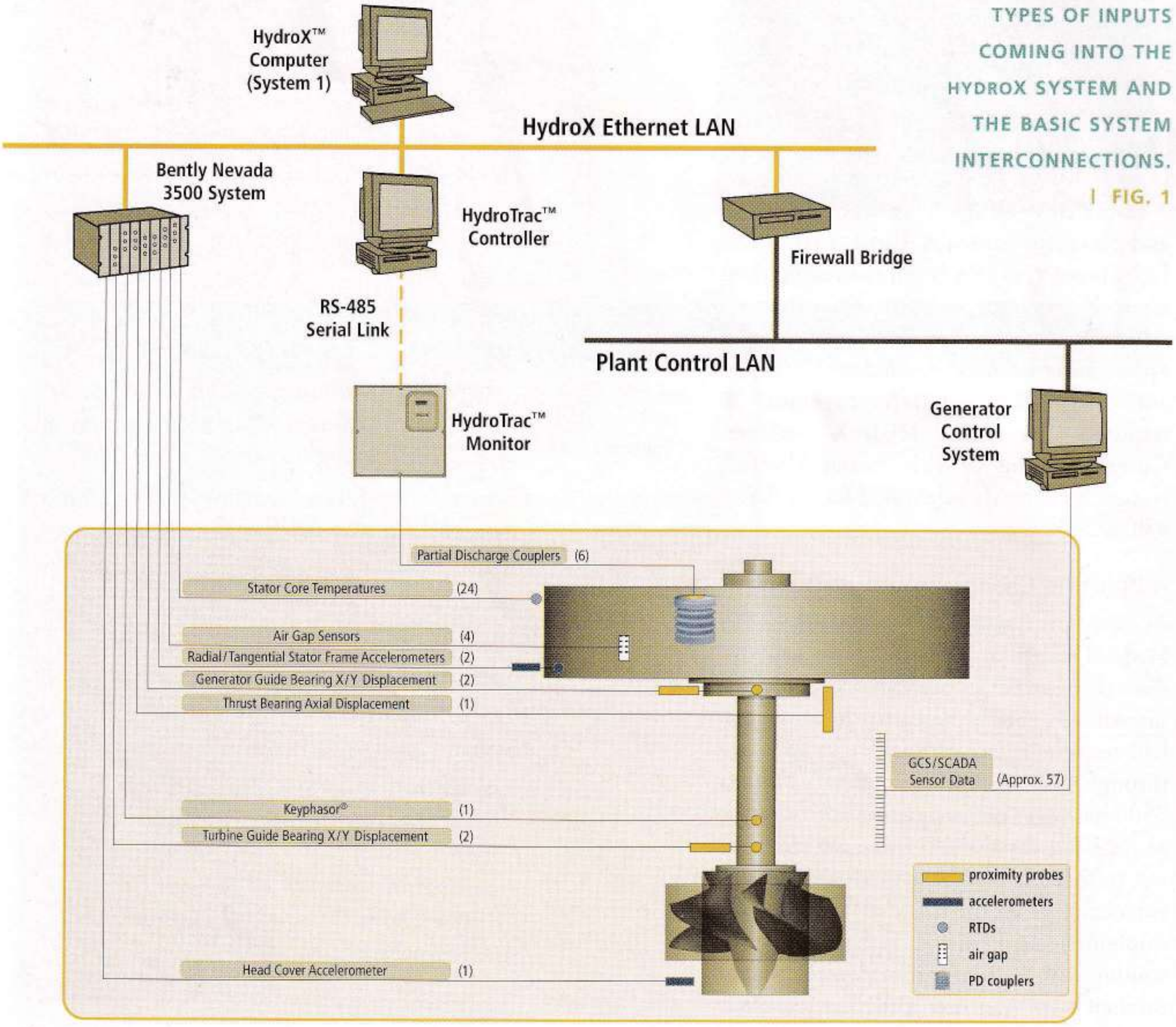
NYPA selected Iris Power Engineering, Inc. of Toronto, Ontario, Canada as lead consultant/contractor for development and implementation of the HydroX system. Iris has extensive experience in electrical condition monitoring for large motors and generators, with particular expertise on hydro generators (Iris was founded by individuals formerly with Ontario Power Generation's Research and

Development department). The company's products include the HydroTrac™ partial discharge monitoring system, a crucial measurement required by the HydroX system for monitoring the condition of insulation on generator stator windings.

Bently Nevada was chosen to provide its 3500 Series Monitoring System for vibration, axial position, bearing temperatures, generator air gap, generator winding temperatures, and speed / Keyphasor® measurements.

The Location

The site chosen for initial application of the HydroX system was the Robert Moses – Robert H. Saunders Power Dam, located near Massena, NY, on the St. Lawrence River and part of the St. Lawrence – FDR Power Project (see photo on pages 62-63). This dam has 32 turbine-generators and is equally divided by the international border between the United States and Canada. The south half of the dam is owned and operated by NYPA


HydroX™ Computer (System 1)
HydroX Ethernet LAN
Bently Nevada 3500 System
HydroTrac™ Controller
Firewall Bridge
RS-485 Serial Link
Plant Control LAN
HydroTrac™ Monitor
Generator Control System
Partial Discharge Couplers (6)
Stator Core Temperatures (24)
Air Gap Sensors (4)
Radial/Tangential Stator Frame Accelerometers (2)
Generator Guide Bearing X/Y Displacement (2)
Thrust Bearing Axial Displacement (1)
GCS/SCADA Sensor Data (Approx. 57)
Keyphasor® (1)
Turbine Guide Bearing X/Y Displacement (2)
Head Cover Accelerometer (1)
proximity probes
accelerometers
RTDs
air gap
PD couplers

TYPES OF INPUTS COMING INTO THE HYDROX SYSTEM AND THE BASIC SYSTEM INTERCONNECTIONS.

| FIG. 1

and has 16 turbine-generators. The north half of the dam and its 16 turbine-generators are owned and operated by Ontario Power Generation.

The plant was originally commissioned in the late 1950s. Each of the units in NYPA's portion of the dam has a nameplate rating of about 60MW and utilizes a vertical fixed-pitch Kaplan-type propeller turbine, driving a GE generator. Eight of the turbines were manufactured by Allis-Chalmers, and the other eight by Baldwin-Lima-Hamilton.

NYPA began a 15-year Life Extension and Modernization (LEM) project in 2000 to upgrade all the generating units. These upgrades include replacement and redesign of the turbine runners, installation of new rotor poles, and rehabilitation of the generator itself with new solid-state excitation and generator controls. Also as part of this LEM project, NYPA is implementing their HydroX system on one unit, since the unit refurbishment activities provide an excellent opportunity to install the necessary sensors and instrumentation (refer to Figure 1) required by the HydroX system. Commissioning of this initial HydroX system is currently scheduled for the latter half of 2004.

A Platform Change

As noted previously, Iris began work on the HydroX system in 2000, under the assumptions that custom software development was unavoidable. Soon thereafter, however, Iris had become aware of System 1® software through their work with the Bently Nevada 3500 hardware being supplied as part of the project. Iris felt that the System 1 platform was sufficiently mature to merit serious consideration as an off-the-shelf solution for implementing HydroX, rather than continuing with custom software development on their own. A recommendation was made

Why System 1?

In their evaluation, NYPA and Iris identified numerous advantages to deploying HydroX on the System 1 platform, including the following:

- System 1 is a mature commercial product, with over 300 man-years of coding behind it. The HydroX project can utilize this development effort, rather than duplicate it. Iris can thus focus on verification, testing, and embedding their hydro condition monitoring knowledge into the tool, rather than developing a tool from the ground up.
- System 1 already enjoys broad use by hundreds of customers, ensuring that GE Energy and Bently Nevada will service and support the platform for many years to come, relieving NYPA and Iris from the burden and expense of trying to support a "one-of-a-kind" application themselves.
- System 1 is a much more flexible platform than the prototype originally envisioned for HydroX.
- System 1 has a robust expert engine, with very flexible rule development and testing, making HydroX easy to implement.
- System 1 already contains support for vibration monitoring sensors and data presentation formats. Bently Nevada is recognized globally for their expertise in this area, and System 1 incorporates this expertise.
- System 1 already contains support for air gap monitoring sensors and data presentation formats.
- System 1 has flexible, industry-standard hardware and software interfaces, allowing inputs from the HydroTrac™ system and the Generator Control System to be easily incorporated now, and other data sources to be easily added in the future without the need for custom interface development.

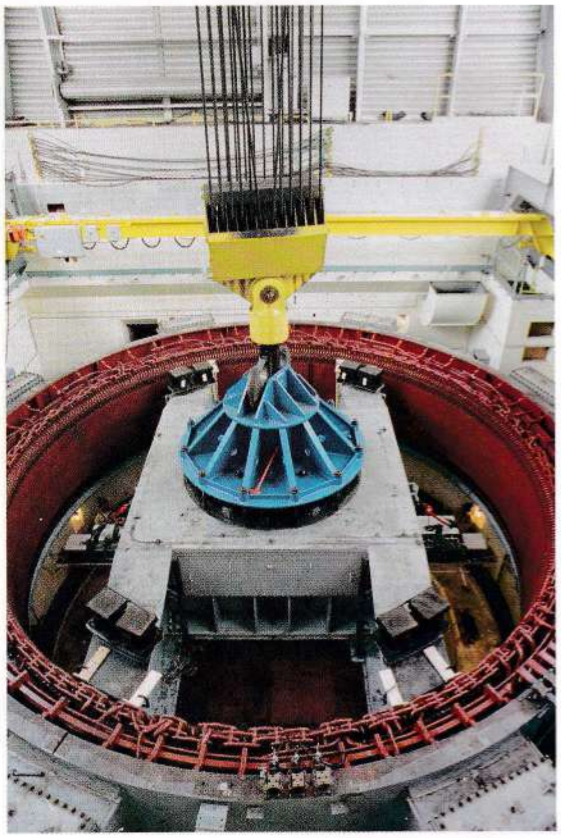
from Iris to NYPA regarding the adoption of System 1 as the platform for HydroX instead of custom development.

Scope

Based on the overwhelming advantages summarized in the sidebar at left, the decision by Iris and NYPA to use System 1 followed quickly, and efforts took on a distinctly different personality as they switched from a custom software development project to an implementation project using an off-the-shelf, commercially proven product.

Scope for the project thus became as shown in Table 1.

(continued on page 70)



THRUST BEARING HOUSING BEING REPLACED ON ONE OF THE UNITS AS PART OF LEM PROJECT.

TABLE 1

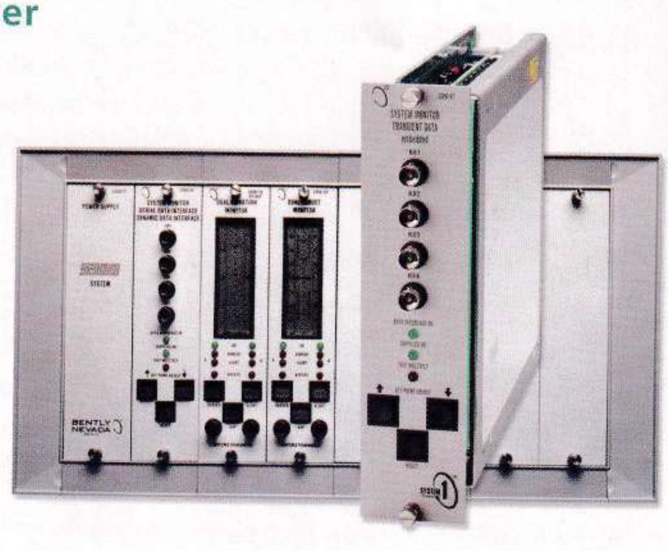
ENTITY	SCOPE	MEASUREMENT POINTS
NYPA	HydroX System mechanical/electrical construction, drawings, and sensors installation. Bently Nevada 3500 cabinet installation and commissioning. Installation and commissioning of the HydroX network and server computers. Complete and furnish the HydroX interfaces such as control system, remote access, and SCADA.	
Iris Power Engineering, Inc.	Development of System 1 Hydro RulePak System Integration System 1 configuration Supply HydroTrac™ Monitoring Systems	Generator Partial Discharge
Bently Nevada	Supply System 1 Software Supply 3500 Series Monitoring Systems	Guide bearing radial vibration Thrust bearing axial position Generator air gap measurements Generator core and winding temperatures Generator Stator Frame casing seismic vibration (radial and tangential) Turbine head cover seismic vibration Once-per-turn (Keyphasor®) phase/speed signal

Integrating 3300 Monitoring Systems to System 1® Software

New Embedded Communications Processor Makes Connectivity Easier Than Ever

Announcing the 3300/02 TDe System Monitor

Bently Nevada is pleased to announce a new communications processor specifically designed to allow easier connectivity of existing 3300 Series Monitoring Systems to System 1 software. Our new 3300/02 Transient Data embedded (TDe) System Monitor module contains a full-featured internally mounted version of our powerful TDXnet™ external communications processor. Its design requires no external hardware, wiring, or mounting space – simply replace the existing 3300/03 System Monitor in your rack with the new 3300/02 TDe.



3300 Monitoring System – Alive and Well

Many customers have asked us whether the 3300 Monitoring System is an "obsolete" product. Our response is that while the 3500 System is recommended for all new installations and represents increased functionality and value, the 3300 product line remains fully supported, even as it passes its sixteenth birthday. Why? Very simply, 3300 remains a viable, reliable machinery protection system with worldwide acceptance. Globally, 3300 monitoring systems number in the tens of thousands, and we have a strong commitment to support our customers rather than institute a forced obsolescence program. Our customers, and Bently Nevada, believe that installed 3300 systems continue to be fit-for-service and there is no compelling reason to upgrade these systems unless the functionality of one of our newer monitoring systems, such as 1701 or 3500, is required. In order to help our customers continue to realize high value from their installed 3300 systems, we have introduced the 3300/02 TDe System Monitor, allowing 3300 systems to more easily connect to System 1® software.

Certainly, in some cases, we are unable to support older products because the electronic components are no longer obtainable from our suppliers. However, in these instances, we plan ahead and communicate with our customers well in advance, generally providing five or more years of advance notification regarding "retirement" of a product line.

We thank you for your overwhelming confidence in the 3300 product line over the years, as evidenced by its exceptionally large installed base. We will continue to stand behind these systems with the service and support you have come to expect from Bently Nevada, continuing our heritage of *taking excellent care of our customers.*

Connecting your existing 3300 racks to System 1 software is, in most instances, now as easy as 1-2-3:

1 Power-down the rack, slide out your existing 3300/03 system monitor module, slide in the new 3300/02 TDe module, and repower the rack

2 Run an Ethernet cable to the 3300 rack(s) and connect to a System 1 host computer

3 Configure System 1 software and start using your new condition monitoring capabilities

You Spoke, We Listened

While the 3500 Monitoring System is today's flagship offering, there are hundreds of thousands of 3300 channels still used in widespread applications around the world, providing reliable service and with significant useful life remaining. With the introduction of the System 1 platform to replace earlier generations of condition monitoring software, a frequent customer request has been an easier and more cost-effective interface to System 1 for their installed 3300 Systems. Our answer? The new 3300/02 TDe.

Zero Footprint, Zero Hassle

A communication processor digitally samples and captures the high-speed vibration and condition data within the monitoring system under a variety of user-configurable states such as alarm conditions, changes in machine rotative speed, and changes in time. It temporarily buffers this data, formats it appropriately, and then provides it to the condition monitoring software where it can be viewed, analyzed, manipulated, trended, and archived.

The extensive computational horsepower to provide such functionality has historically required a separate externally mounted box, roughly the same size as the underlying monitoring system. However, dramatic advances in digital signal processing technology over the last few years have allowed us to shrink the size of our communications processors, eliminating the need for an external module and instead embedding these capabilities *inside* the existing monitoring rack, requiring only the replacement of a single module.

Scalable Pricing and Configuration

The 3300/02 TDe System Monitor can provide static, steady-state, and/or transient data collection capabilities. Pricing is a function of the number of channels

No Ethernet? No Problem.

As we consulted customers regarding the new 3300/02 module and ways that we could make it retrofit-friendly, several told us that pulling Ethernet cable out to their existing 3300 racks would be difficult – if not downright impossible. New installations can, of course, easily pull this cable during the construction phase, but existing installations face a more difficult challenge.

Because customers almost always have one or more spare twisted-pair cables available between their cabinets (where the 3300 rack is mounted) and a control room (where network connections are located), available physical wiring often *does* exist – but not Ethernet cable. Fortunately, Bently Nevada offers an innovative, pre-engineered media converter solution that allows this network connection to be carried over a standard twisted-pair cable, and then converted back to conventional Ethernet cable once in the control room. The result is reliable, hardwired network connectivity, without the inconvenience and cost of pulling new wires.

from which data will be collected and the type of data collected from each channel. You pay only for what you need, allowing a scalable and affordable solution that is tailored to your application.

Compatibility

The new 3300/02 TDe System Monitor module is compatible with 3300 racks manufactured since 1992 with an enhanced-style backplane. Your local Bently Nevada sales professional can assist you in establishing the compatibility of your specific 3300 racks and monitoring modules. You can also find compatibility information on our website at www.bently.com.

Those customers with an existing serial data interface connection between their 3300/03 System Monitor module and a process control system (such as a DCS) can use the same cabling to connect to the 3300/02 TDe module. No reprogramming or cabling changes are necessary[1].

System 1 software version 5.0 or later[2] is required for communication with 3300/02 TDe-equipped racks.

Extended Support

Many 3300 Systems were commissioned years ago and are well beyond their original warranty. However, you can combine the installation of a 3300/02 TDe System Monitor with optional extended warranty coverage for your racks. At the same time a Bently Nevada service engineer installs your 3300/02, he can also ensure the rest of your 3300 rack is operating within specifications and provide you with an extended 3-year warranty for the entire[3] 3300 rack, not just the 3300/02 module.

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1. If the connection from the 3300 rack to the DCS uses RS-232 communications, customers will need to unplug this cable and move it to an adjacent serial port (less than 50 mm away) on the back of the 3300 rack. Customers using RS-422 communications do not need to move the cable.
2. System 1 software version 5.0 shipped prior to July 2004 requires a downloadable upgrade for 3300/02 TDe compatibility.
3. A very small percentage of 3300 module types are no longer produced and are not available for extended warranty provisions. Contact your Bently Nevada sales professional for additional information on specific 3300 module types affected.

HydroX (continued from page 67)

Hydro RulePak

A standard part of System 1's Decision Support functionality is the use of RulePaks. A RulePak is simply a collection of rules that System 1 uses to analyze its collected data. Rules are generally specific to a certain type of machine, process, or malfunction. Rules can be grouped into a package that addresses a particular area of interest such as "hydroelectric turbine-generators" or even a specific make and model of machine. Special "developer editions" of Decision Support are available, allowing machinery OEMs, end users, and others with relevant subject matter expertise to create pre-configured RulePaks that can be shared with others. For example, an OEM might want to create a RulePak for specific makes and models of its generators. Or, a large company with numerous similar process plants in multiple locations might wish to create RulePaks specific to particular processing units that can be used across their enterprise, without the need for individual facilities to create their own rules.

This capability of System 1 was very significant to the HydroX project. A key part of the HydroX vision was to be able embed hydro-specific diagnostic knowledge into the system. With System 1's ability for the easy creation of RulePaks, and the ability for the author of a RulePak to restrict access of the underlying rules to only authorized personnel, rules can be shared and implemented while protecting the underlying intellectual property, much as application software can be used without divulging the underlying programming code. Iris is making extensive use of these capabilities in developing the RulePak used by HydroX.

Next Steps

Commissioning of the first HydroX system is slated for the latter half of 2004. It will be on unit 18 at NYPA's St. Lawrence – FDR Power Project. Once the HydroX system has proven successful, NYPA plans to install it on the other 15 units at this facility.

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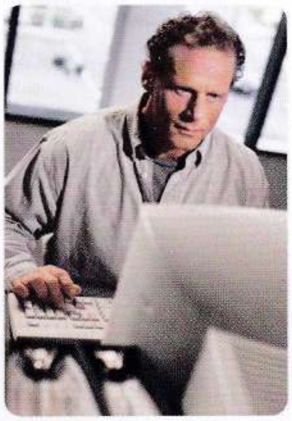

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